PROSPECTING *for* OIL AND GAS

BY

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TO

HELEN M. PANYITY

PREFACE

At the present day many people are greatly interested in oil and gas, but the impression among most inquirers is that the discovery of oil and gas accumulations is a matter of chance, and although this number is gradually diminishing, still even among practical oil men geological evidences are quite often neglected. This is due to the fact that the methods of the geologist are not understood, and in many cases prejudice against him has hindered his work and prevented co-operation between the scientific and the practical investigator.

To that class who are interested only in the investing or speculating features of the industry, geology is almost unknown. Advertisements or prospectuses of oil and gas ventures are often coupled with a geological report, and whether such report is merely an extract or is given in full, the investing public is unable to analyze its contents and pass judgment upon its merits.

There are valuable books written on this subject, the majority of which are intended for the professional geologist, and although invaluable to him, they are too technical or cover only a certain branch of oil and gas prospecting and producing. The professional geologist will notice that in this book an attempt is made to put before practical oil men and the general public the various tools and methods of the scientific oil and gas prospector of the present day, avoiding lengthy discussions and confining its scope mostly to descriptions and explanations, by means of which it is hoped that those interested will be brought into a more intimate relationship with the geologist, and thus they may realize just what may be expected of him and how much service he may render in eliminating a great number of unnecessary chance methods frequently used at the present day.

Another class of readers to whom the author hopes this treatise will be of assistance is composed of those who intend to take up and follow the profession of Oil and Gas Geology. For them it may serve as an elementary work on the subject and form an outline of the various phases of study that make up this subject. They will find the different branches of the science treated briefly, and along those lines which will lead the student in his further study and researches. In short, the methods of the leading oil and gas companies are described in a brief manner, and those investigating will find them in this volume.

The writer is indebted to the authors of a number of valuable books which have been consulted in the preparation of the manuscript, among which are the excellent reports and publications of the United States Geological Survey and the Bureau of Mines, as well as those of the various State geological publications, namely Pennsylvania, West Virginia, Ohio, Oklahoma, Texas and Wyoming. The Transactions of the American Institute of Mining Engineers, as well as the various books on allied subjects, such as Johnson & Huntley's excellent book, "Principles of Oil and Gas Production," Dorsey Hager's "Practical Oil Geology," Victor Ziegler's "Popular Oil Geology," Grabau and Shimer's "Index Fossils," and Shimer's "Introduction to the Study of Fossils" have also furnished valuable assistance. Further acknowledgments are made along with the illustrations in the book.

The author wishes not only to give credit and thanks to these authors, but also to recommend their works to those who intend to go into the study in greater detail.

A great many practical procedures have been acquired from numerous practical oil men, with whom the writer has had enjoyable business relations, and from whom many "wrinkles" have been learned, and it is hoped that this book will assist in strengthening this relationship which may be long continued.

To the officers of The Ohio Fuel Supply Company, as well as the great number of friends and "co-workers" with whom the author has associated during the past five years, he is indebted for a number of the practical forms that are used; and to Mr.

Herbert W. Hancock of the Drilling Department, for the complete Drilling Contract.

Special mention is due Mr. Roswell H. Johnson, Professor of Oil and Gas Production at the University of Pittsburgh, whose teachings of the fundamental principles of Oil and Gas Geology have been the foundation of this book.

L. S. Panyity.

Columbus, O.
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CHAPTER I

COMPOSITION AND PROPERTIES OF OIL AND GAS

PETROLEUM and natural gas are among the most important natural resources of the present day. From the crude petroleum refined products are obtained by various processes of distillation, and natural gas is utilized wherever heat and fire may be needed, with excellent results.

Oil and gas are composed of a mixture of hydrogen and carbon, hence known as hydrocarbons. There are also oxygen, nitrogen and sulphur present in various amounts, but merely as impurities.

One speaks of crude oil as having either a paraffin or an asphalt base, depending on the residue remaining after the evaporation of the lighter constituents, which gives rise to several classifications to which hydrocarbons so readily lend themselves. In so far as the oil and gas industry is concerned, two classifications are of importance, namely, the paraffin series (oils containing paraffin for a base), and the olefine and naphthene series (oils containing asphalt for a base).

Chemical analysis of hydrocarbons shows that the members forming the paraffin series are composed of hydrogen and carbon in a regular ratio, that is, the number of hydrogen atoms are equal to twice the number of carbon atoms plus two; this relation is represented by the generalized formula C_nH_{2n+2}. The value of such formulæ will be apparent when the various members belonging to these series are classified.

The most volatile member of the paraffin series is Methane,

or Marsh Gas (CH_4); which forms an important part of natural gas, also found in swamp and coal gases. Increasing the proportion of the composing elements to the next step, we have Ethane (C_2H_6), which is also a gas, but with different properties than Methane. The differences of the various members have an orderly relation to each other which may be described briefly as follows: Methane, Ethane, Propane and Butane form the gaseous members, the boiling-points of which are increasing in order, which for Methane is $-165°$ C. and that of Butane $+1°$ C., and as the boiling-points become higher the liquid and solid members are formed. The specific gravity of the various liquids as well as of the solids increase with the general rising of their boiling points.

The lower members of the paraffin series, which are especially characteristic of Pennsylvania petroleum, are given in the following list:

Name.	Formula.	Boiling Point C.°*	Gravity at 60° F. (Bé).
1. Gaseous			
Methane	CH_4	−165	
Ethane	C_2H_6	− 93	
Propane	C_3H_8	− 45	
Butane	C_4H_{10}	+ 1	
2. Liquid:			
Pentane	C_5H_{12}	36.3	92
Hexane	C_6H_{14}	69	85
Heptane	C_7H_{16}	98.4	76
Octane	C_8H_{18}	125.5	71
Nonane	C_9H_{20}	150	66
Decane	$C_{10}H_{22}$	173	63

*Boiling Points, from F. E. Fowle, in Smithsonian Physical Tables.

The classification of the olefine and naphthene series is similar to the above, the generalized formula being C_nH_{2n}.

Although the systems given above are sufficient for the needs of the oil man, they are not the only ones in use, as there are numerous other regular series, and the generalized formula for some of them is given below:

1. C_nH_{2n+2} .... Paraffin
2. C_nH_{2n} .... Olefine and Naphthene
3. C_nH_{2n-2} .... Acetylene
4. C_nH_{2n-4} .... Rare
5. C_nH_{2n-6} .... Benzene
6. C_nH_{2n-8} .... Rare

In some fields the crude oil carries both asphalt and paraffin for a base, and such are known as mixed base oils.

Determining the specific gravity of crude oil is the most common test applied by the oil man. In order to simplify the ordinary specific gravity figures (which are obtained by the comparison of the weight of oil with the weight of an equal volume of water under similar conditions), a system known as the Baumé scale is in use. On this scale water having a specific gravity of 1° is placed at 10°. The specific gravity of oil is less than that of water, but the figures on the Baumé scale are so arranged that they increase as the specific gravity becomes less, so that the heavier oils will have a lower gravity and the lighter oils a higher one on the Baumé scale. It is possible to calculate the specific gravity from the Baumé figure by dividing 140 by the sum of 130 and the Baumé degree. This operation may be expressed in the form of a formula

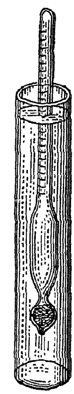


FIG. 1.—Hydrometer.

$$\frac{140}{\text{Bé.}^\circ + 130} = \text{Specific gravity.}$$

Thus, if the Baumé gravity of oil is 36° its conversion into specific gravity will be as follows:

$$\frac{140}{36+130} = \frac{140}{166} = 0.8434 \text{ Sp. gr.}$$

A hydrometer, equipped with the Baumé scale, is in general use in establishing the gravity of the oil. The instrument is

simply immersed in the liquid and the result is read direct from the scale. (Fig. 1.) In general practice the gravity of oil is

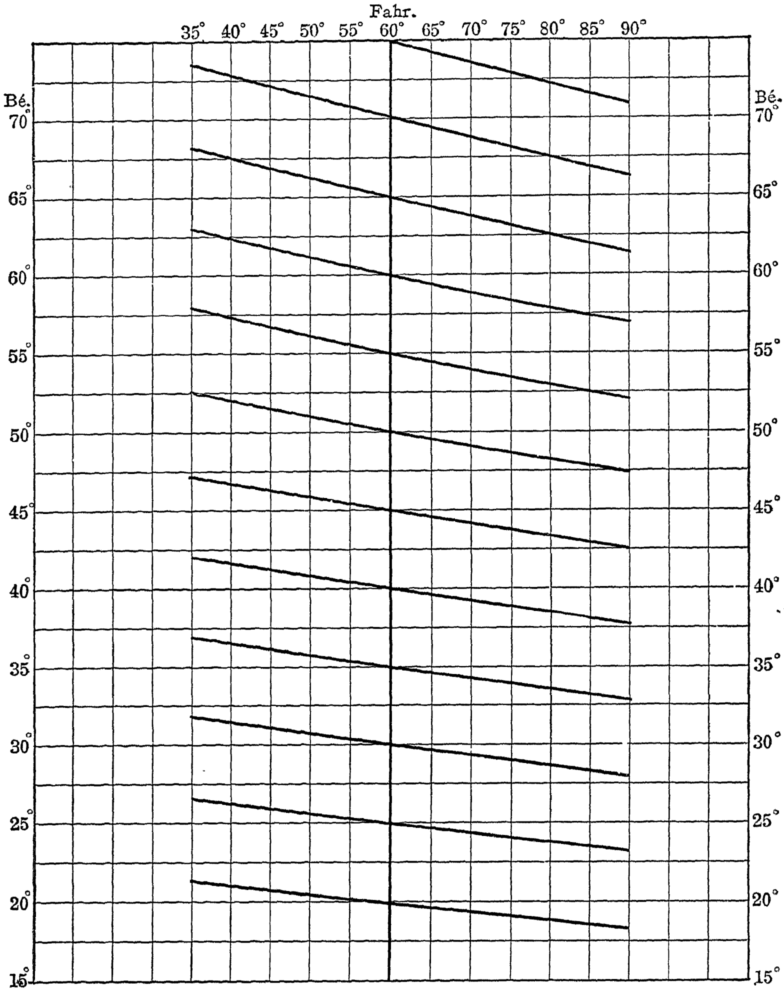


FIG. 2.—Effect of Change of Temperature on Baumé Scale Gravity of Oil.

based on results obtained at 60° Fahrenheit, so it is necessary to make an allowance for readings taken when the temperature of the oil is more or less than 60° F. Most hydrometers are

equipped with a thermometer, as well as with instructions as to how much allowance is to be made, but if, however, this is not

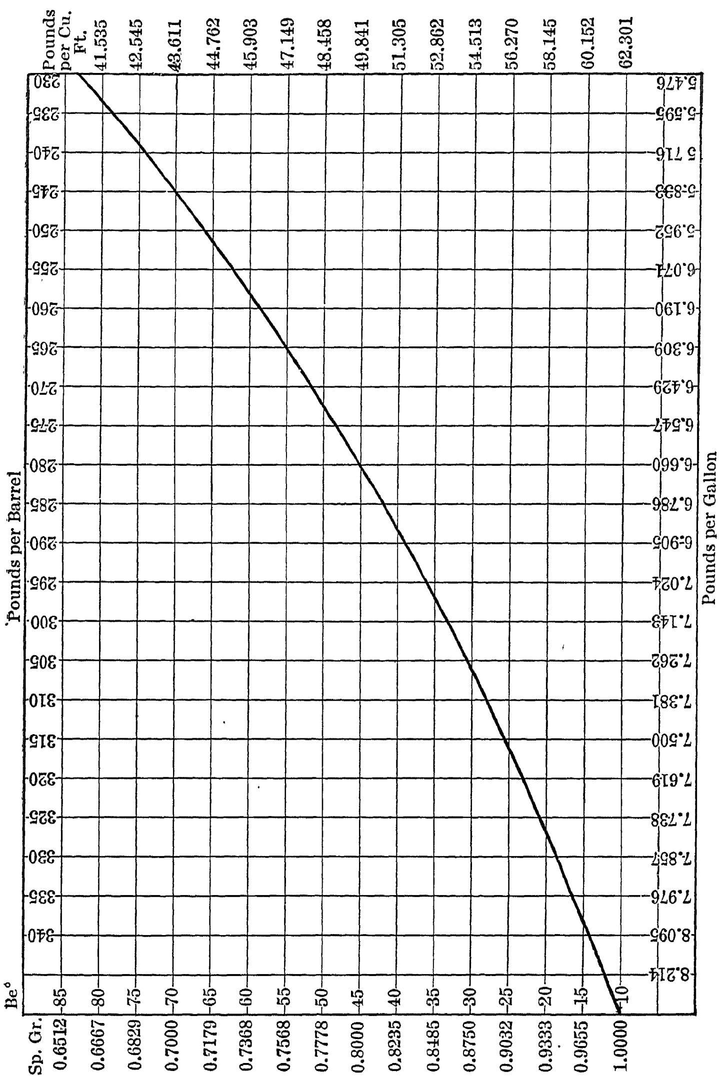


FIG. 3.—Graph Showing Relation Existing between Gravity and Weight of Oil.

the case the user is to make his own adjustment. A graph constructed for that purpose may be used. (Fig. 2.)

The weight of a barrel of oil varies with the change of its gravity, and the relation existing between the gravity and the pounds of oil per barrel is shown by the curve in Fig. 3. A rapid calculation of the weight of a barrel of oil may be made by use of it.

Paraffin base oils generally have a higher gravity than the asphalt base oils, also the color of the oil may give some clue as to its classification, as the paraffin oils are much lighter in color than are the asphalt oils, which are quite dark or black. The color of crude oil ranges from bright yellow to black, depending of course upon its composition.

The odor of oil and gas differs in various localities, but the main point of difference noticeable is between the limestone oils and gases and those produced from sandstones. Limestone oil and gas may be recognized from the strong odor of sulphureted hydrogen, which is not only disagreeable, but may injure or blind the eye if exposed to it for a considerable length of time. Gases from other sources do not act in such a manner.

California and parts of Texas produce asphalt base oils, Illinois a mixed base, and the main production of the remainder of the oil-producing States are paraffin oils.

CHAPTER II

ORIGIN OF OIL AND GAS

SINCE the beginning of the 18th century various theories have been advanced for the origin of oil and gas, but even at the present day the controversy is still active. The general nature of the theories places them into two distinct classes: the inorganic and organic theories.

Inorganic Theories. The followers of the inorganic theory base their statements on the assumption that as hydrocarbons, resembling petroleum, have been produced in the laboratory by the action of carbonic acid upon alkali metals, that similar reactions may take place at great depths and that hydrocarbon compounds may be produced by the reaction of water charged with carbon dioxide, upon metals and alkalies at high temperature.

This Carbide theory meets the requirements of the chemist, but the conditions under which oil and gas are actually found have been disregarded. It is possible that carbides exist at great depth, and no doubt heat is also present, but the fact that known pools lie in a zone where no trace of either may be found is against this theory. Rocks forming oil and gas reservoirs show without a doubt that they have never been subjected to great heat. Igneous and metamorphic rocks, which may be the source of the necessary carbides and also permit the presence of the necessary heat, have nowhere been found to contain oil or combustible gas in commercial quantities, although they would be considered as the probable place for the origin of petroleum according to this view. Present oil pools are not found in the existing igneous and metamorphic rocks, but separated from them, sometimes by great thicknesses of fine-grained rocks, and the possibility of the oil and gas migrating

towards the surface, great distances, through these practically impervious strata, is out of the question.

Another inorganic theory is known as the Cosmic theory, which is based on the finding of small amounts of hydrocarbons in meteorites, but as this theory has no other foundation it may be dismissed without further discussion.

Some hydrocarbons have also been found in connection with volcanic emanations, and a theory based on these findings places the source of the hydrocarbons at great depth, and the present accumulations are claimed to be subsequent infiltrations and impregnations from such depths. The followers of this theory point to the fact that gas pressure increases with depth, which is believed to be due to the fact that the source is very deep.

Organic Theory. Although it may be admitted that certain amounts of hydrocarbons may have been formed according to the inorganic theory, the commercial deposits point to entirely different probabilities, with which most oil and gas geologists are in accord. There are several variations of the organic theory, but in each case organic matter is claimed to be the origin of oil and gas. Certain classes claim vegetable matter to be the source of petroleum and gas, while others attempt to show that animal matter is the most probable source, and there are also many who point to the possibility of both animal and vegetable matter being the organic materials from which the hydrocarbons have been formed. Petroleum and natural gas compounds may easily be derived by the destructive distillation of organic matter.

Decay of vegetation at ordinary temperature gives rise to light, carbureted hydrogen if air is excluded, and the action of bacteria causing organic decay is also admitted.

Geological conditions show that the factors at hand are: water, pressure and time, which combined with the organic remains in the rocks are sufficient to permit the formation of oil and gas. Commercial accumulations that are found are in all cases in accord with this theory.

One of the most important facts bearing on the organic theory has been brought forth by the examination of oils under the petrographic microscope. It has been observed that oils when

studied between Nicol prisms will rotate a ray of polarized light, and it is claimed that only oils derived from organic matter can possess this property. No doubt studies along these lines are of great importance to settle finally the origin of oil and gas so that it may be accepted without further question.

The common conception among oil and gas geologists, with few exceptions is, that oil and gas are of organic origin, produced under relatively low temperature, high pressure and with the possible assistance of bacteria.

CHAPTER III

GENERAL GEOLOGY

In order that a better understanding of the geology of oil and gas may be had, it is necessary that one should become familiar with the fundamental principles of rocks and their formation. It is known that the earth is a large sphere of about 8000 miles in diameter, having a comparatively thin rocky crust, or lithosphere, with which the geologist is mainly concerned, as it is the only accessible portion of the earth for a general study. Oil and gas, as well as our precious metals and minerals, are found in the lithosphere.

The rocks of the lithosphere are divided, according to their mode of origin, into three great classes known as the igneous, metamorphic and sedimentary rocks.

Igneous Rocks. Igneous rocks have been formed by the cooling and solidifying of hot molten masses, becoming crystalline or glassy and compact. Originally they were at very high temperature, so no living animals or plants were in them at the time of their formation, and are, therefore, unfossiliferous, and as they are found in almost any form and shape imaginable, are spoken of as unstratified rocks. *Rocks of this class have a very low percentage of porosity, and are, therefore, unsuitable for oil and gas accumulations.* Granite, diorite and basalt are typical rocks of this class.

Metamorphic Rocks. Rocks, whether igneous or sedimentary, that have undergone some sort of a change or reconstruction, either physically or chemically, are known as metamorphic rocks. Metamorphism may be due to various causes, such as the rearrangements of the molecules caused by pressure or by the contact of igneous and sedimentary rocks. Hydration and dehydration may bring about certain changes; oxidation

or reduction as well as percolating waters and gases also cause metamorphism. These rocks are quite compact and crystalline, thus unsuitable for oil and gas reservoirs. It is possible, however, that dissolving agents, such as percolating waters and gases, acting upon metamorphic rocks, may make them more porous; and such may accumulate oil and gas if in contact with sedimentary rocks; however, *rocks of this class are not important in this connection and may be dismissed as a factor for oil or gas*

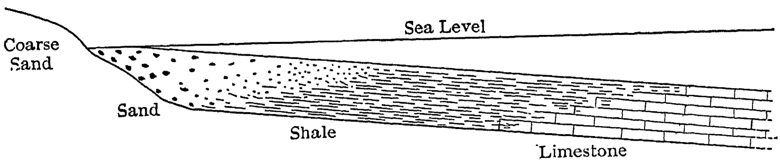


FIG. 4.—Order in which Sediments are Deposited away from the Seashore towards Deeper Water.

accumulations. Gneiss and schist are examples of metamorphic rocks.

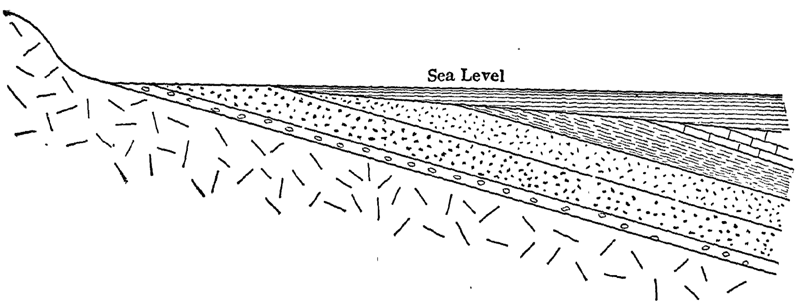
Sedimentary Rocks. Rocks which have been formed from the eroded particles of existing rocks and deposited in layers, generally by water, sometimes by winds or glaciers, are known as sedimentary rocks. (Fig. 4.) They are deposited in nearly horizontal layers and contain the remains of plants and animals, known as fossils, which may be microscopic in size or larger. *Sedimentary rocks are porous to a greater extent than are igneous and metamorphic rocks, hence suitable for oil and gas reservoirs.*

SEDIMENTATION

It is well known that the original surface of the earth has undergone a great change. The gases of the atmosphere, such as nitrogen, oxygen, carbon dioxide and water vapor are very strong agents of erosion; the rocks being exposed to atmospheric influences are constantly denuded by the dissolving effect of percolating waters, the carving strength of strong winds and the splitting force of frost, and are worn away, and the eroded particles are carried by winds, waters and glaciers and deposited

at various places. The result of erosion upon the earth's surface is the formation of hills and valleys.

The general level of the land is constantly changing (diastrophism); portions formerly under sea level being elevated and vice versa. Submergence of the strata permits the encroachment of the sea, and the deposition of the eroded rock particles that are carried in suspension by the water (Fig. 5), forming nearly horizontal sediments, strata upon strata. Alternate rising and sinking of the land level allows for further erosion and deposition, so that former hills and valleys may be obliterated and new ones formed. This process might be continuous, or



1, older rocks; 2, basal conglomerate; 3, coarse sandstone; 4, sandstone; 5, shale; 6, limestone.

Fig. 5.—Result of Sea Transgression, Showing the Order in which the Sediments are Laid Down.

again be interrupted for a great length of time, causing a *hiatus* or unconformity between the sediments. (Fig. 6.) Deposition is a slow process, but during the great geological ages the amount of sedimentary rocks that have been formed this way are enormous.

Certain geologists have represented the world as having a heaving crust—parts rising and sinking. Others represent the earth as a shrinking globe, but whatever the cause, the results upon the rocks are the same. The various thrusts and forces deform the almost horizontal sediments, tilting and folding them in every conceivable way. Changes of this kind in the rocks are accompanied by dislocations or faults. (Fig. 7.) Supposing

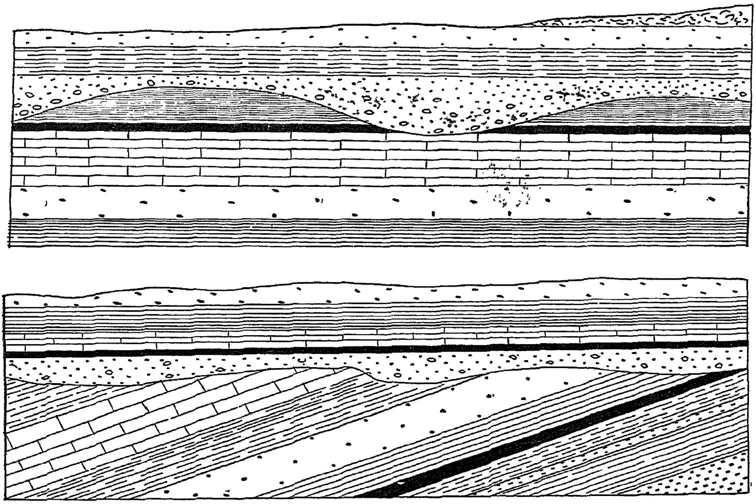


FIG. 6.—Horizontal Unconformity (above); Angular Unconformity (below).

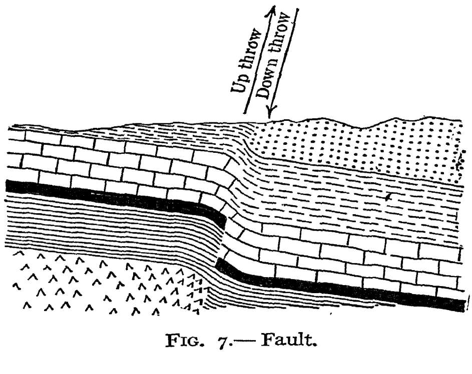


FIG. 7.— Fault.

that after folding another rising and lowering of the land level takes place, further erosion and deposition may become possible upon the already deformed sediments, causing more and more complicated folding and unconformities, or perhaps obliterate previous folds. It is the folds and sometimes the faults as well, that have a great bearing upon commercial oil and gas accumulations, and hence the necessity of a careful study of folds and faults in the sedimentary rocks for a possible clue in locating oil and gas.

Climatic changes no doubt follow an extensive disturbance of the land level and such changes cause variation in the animal and plant life.

The Sedimentary Rocks

The most common sedimentary rocks are: shales, sandstones, conglomerates, limestones, coals and glacial deposits. (Fig. 8.)

Shale. Shale is formed by the consolidation of fine mud, deposited some distance from shore, and upon compacting forms a close-grained rock having an uneven and slaty structure. It is a fragile, argillaceous rock, of various colors such as gray, brown, red and black. As a shale is composed of closely packed fine particles its porosity is very small and therefore impervious to the movement of water, oil and gas to a great extent. Due to great pressure shales become more and more compact and less hydrous, thus forming slates.

Sandstone. A consolidation of sand grains due to the recementation of eroded particles, form sandstones. They are deposited in shallow water along the shore line, and the particles are cemented together by insoluble substances such as silicates, iron hydroxides and calcium carbonate. Sandstones are considered as porous rocks, the porosity varying with the shape of the grains, the kind and amount of cementing material holding them together, and the compacting of the sediments. Different figures have been given for the porosity of sandstones, which vary from 5 per cent up. Due to this porosity sandstones are very suitable rocks for oil and gas reservoirs, their porous portions permitting accumulations in commercial quantities. (Fig. 9.)

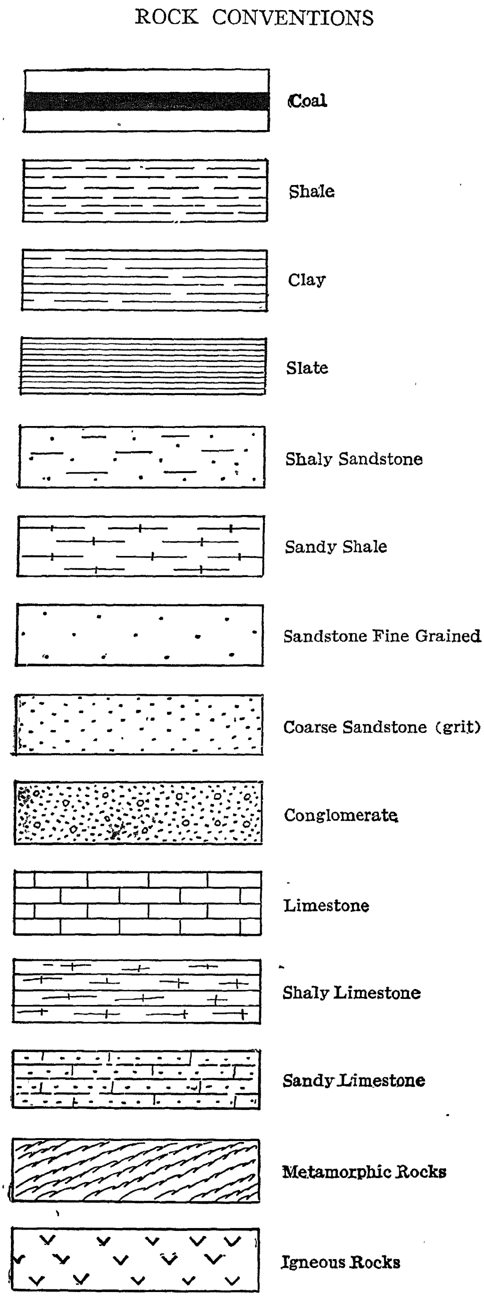


FIG. 8.—Conventions Representing the Various Rocks.

Conglomerate. As the name implies, a conglomerate is a combination of rather large sand grains or pebbles, cemented together. It may also form a reservoir for oil and gas.

Limestone. Limestones consist of calcium carbonate ($CaCo_3$) with impurities. The calcium carbonate may be from various sources, quite an amount of it is obtained from marine animals. Limestones are generally deeper water deposits, and therefore carry animal and plant remains or fossils; the study of which enables us to recognize and correlate formations from different parts of the globe. A calcium carbonate rock is too compact to be considered as oil and gas reservoir rock; however, the dolomitic

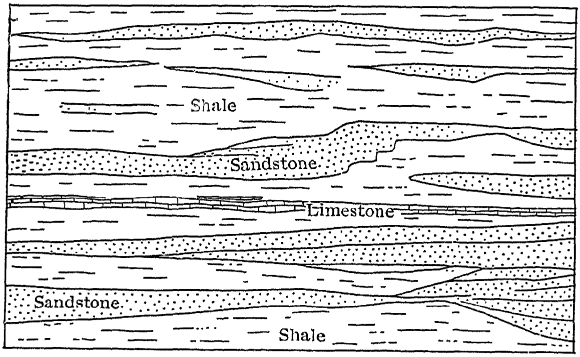


FIG. 9.—Cross-section Illustrating Lenticularity of Sandstone Beds. Vertical scale very much exaggerated. (U. S. G. S. Bul. 691–c.)

form of limestone composed of calcium magnesium carbonate ($CaMgCo_3$) is porous enough if the magnesium contents are at least 25 per cent. A fossiliferous limestone is not porous enough for oil and gas accumulations, and a pure calcium carbonate limestone can only be considered as a possible reservoir rock if it is sufficiently water channeled, or if it is fissured.

Coal. Depositions of carbonaceous matter, such as coal and lignite, are formed from vegetable matter and are quite commonly found in a number of the oil fields. They make excellent key-horizons for the driller and geologist. In a few places in West Virginia and Ohio they have been known to contain oil and gas in considerable quantities.

Glacial Deposits. In countries within the limits of former glaciation, great deposits of sands and gravels, as well as boulders, may be found that have been accumulated from glaciers. The glaciers may have obliterated former hills or formed valleys and at the time of their melting, the sands and gravels carried by them filled up the valleys and covered the existing outcropping rocks, thus making the finding of such outcrops difficult; therefore glacial deposits are rather a hindrance to the prospector. They do not contain oil and gas, but have in few instances (Lodi, O.) served as barriers to movements of oil and gas, preventing their escape at the outcrop of the oil containing rock.

Regarding shales, sandstones and limestones, it is rather difficult sometimes to draw a distinct line between them, as they may readily grade into one another, forming shaly sandstones, sandy shales, calcareous shales, or shaly limestones; calcareous sandstones and sandy limestones. Such are known as transitory rocks.

To the uninitiated these great deposits appear to be nothing but a heap of rocks without any semblance of order, yet from this seeming chaos not only have the rocks been systematized but have been arranged in order of their ages or succession of deposition. This was made possible by the study of the fossils found in the rocks.

GEOLOGICAL FORMATIONS

The geological column has been divided into four great sections known as eras or groups and beginning with the oldest are known as the Eozoic, Paleozoic, Mesozoic and Cenozoic Eras. Each era is divided into several ages called periods or systems, which are in turn further subdivided into epochs or series. (Table I.)

TABLE I

GEOLOGICAL CHART

Age.	System or Era.	Period.			Formations and Subformations.
Man	Psycho-zoic	Recent			Modern alluvium, formed by water, wind, glaciers, coral polpy, etc. Ancient village debris, mounds, mines, canal, and railroad grading, quarries, etc.
Mammals	Cenozoic	Pleistocene	Post-glacial	Terrace Epoch	Terraces along river valleys, lakes, seashores in higher latitudes.
				Champlain, or (Ice-Melting) Epoch	High level alluvial plains and "second bottoms" in the North, playas (mud-flats) and later adobe (clay) deposits in the West. Marine and lake clays in Hudson, Champlain, and New England Valleys. The inland beaches and deposits of the interior. Leda clays, Saxicava sands, Algoma sands, with marine and lacustrial beaches and deposits in Canada.
			Glacial	Third Glacial Epoch	Terminal moraines and most aqueo-glacial deposits of Northern United States and Canada; also of Rocky Mountains and Sierras, probably under lake beds of Bonneville and Lahontan.
				Second Interglacial Epoch	Local forest beds, buried soils, and alluvial deposits. Epoch principally represented by erosion.
				Second Glacial Epoch	"Upper Till" of the interior, with most of the loess of the Missouri and Mississippi Rivers; older glacial deposits toward northern border of United States and Canada.
				First Interglacial Epoch	Principal forest bed of Iowa, Illinois, and other interior States with old soils. Nodules and other ferruginous accumulations. Also represented by erosions toward the Atlantic Coast.
				First Glacial Epoch	"Lower Till" of the interior and extra-morainic drift of Pennsylvania and New Jersey. Part of the loess, yellow loam, and Port Hudson clays of Mississippi, with the formation in the Eastern United States. Not identified with glaciation during later epochs.
		Neocene			ATLANTIC AND GULF AREA: Lafayette, Chesapeake, Chipola, Chattahoochee; Sumter, Grand Gulf, Pascagoula; Reynosa, Fayette Beds. INTERIOR: Loup Fork Beds, Ticholeptus Beds, White River Beds, John Day Beds

Mammals	Cenozoic	Eocene	ATLANTIC AND GULF AREA Vicksburg, Jackson } White limestone { Ashley and Cooper Beds, Santee Beds Pamunkey of Md. and Va. { Claiborne, Meridian (Buhrstone), Lignitic	INTERIOR Upper { Uintah Beds, Bridger Beds, Huerfano Beds Middle { Green River Beds, Wind River Beds, Amyzon Beds, Manti Beds Lower { Wasatch, Puerco, Denver, Arapaho, Laramie, in part	PACIFIC AREA { Tejon, Puget, in part
Reptiles	Mesozoic	Cretaceous	ATLANTIC AND GULF AREA Severn { Tombigbee (Rotten limestone), Ripley Raritan Potomac { Eutaw, Tuscaloosa	INTERIOR Laramie, in part (brackish water) Montana (marine) (Salt Wells) { Fox Hills, Fort Pierre Colorado (marine) (Sulphur Creek) { Niobrara, Benton { Woodbury, Fort Dodge Dakota (marine) (Henry Fork) } Nishnabotna TEXAS AREA Comanche Series { Washita, Fredericksburg, Trinity	PACIFIC AND CANADIAN AREA Puget (marine), in part Nanaimo Chico (marine) Wallala Belly River (non-marine) Queen Charlotte (chiefly marine) Kootanie (non-marine) Shasta, Horsetown } Correlation uncertain
		Jura-Trias	ATLANTIC SLOPE AREA Rhaetic of Virginia Newark formation { Acadian area, Connecticut, Palisade, Richmond, Va., and Dan River, N. C., area	} Apparently contemporaneous	ROCKY MOUNTAIN AND PACIFIC SLOPE AREA Red Beds { Star Peak Group, Auriferous slates, in part

TABLE I—*Continued*

Age.	System or Era.	Period.	Formations and subformations.				
Acrogens	Paleozoic	Carboniferous	Permian—Permo-Carboniferous				
			Pennsylvanian	Monongahela Conemaugh Allegheny Pottsville	Appalachian	Limestones, shales without coal of Utah, Wyoming, and California	
			Mississippian	Genevieve	Chester St. Louis Warsaw	Mississippi Valley	
				Osage	Keokuk Burlington	Mississippi Valley	
				Chouteau or Kinderhook	Chouteau of Missouri Kinderhook of Illinois and Iowa Waverly of Ohio Marshall of Michigan	Cuyahoga shale Berea shale Berea grit Bedford shale	Mauch Chunk and Pocono sandstone of Northeastern Pennsylvania
Fishes		Devonian	New York	Catskill sandstone—Catskill		Ohio shale	Cleveland Erie Huron
				Chemung Portage and Oneonta Ithaca	Chemung		
				Genesee Tully Hamilton Marcellus	Hamilton		
				Onondaga limestone Schoharie grit Caudagalli grit	Corniferous	Iowa	Hackberry shale Cedar Valley limestone Independence shale
				Oriskany sandstone—Oriskany			

Invertebrates	Paleozoic	Silurian	Helderberg limestones Tentaculite and Water-lime (easterly) Salina (westerly) Niagara limestone Clinton Dyestone or Rockwood Medina sandstone Oneida conglomerate. Clinch sandstone, Tennessee
		Ordovician	Lorraine and Cincinnati terrane. Nashville terrane
			Utica slate. Maqnoketa. Iowa slate. Galina limestone. Quebec series Trenton limestone (Black River and Bird's-eye). Chazy limestone, New York Calciferous { Calciferous sandstone, Mohawk Valley; Knox dolomite, Tennessee; Oneota limestone (magnesian) Upper Mississippi Valley; Levis Beds, Canada } Hudson River series
		Cambrian	Potsdam { Oneota limestone, Upper Mississippi; Sandstone, Potsdam, New York; St. Croix, Knox Dolomite, Connasauga Beds; Tonto and other limestones, sandstones, and shales Acadian { Slates of Braintree, Massachusetts; Slates of St. John, New Brunswick; Limestones of Stissing, New York, Tennessee, Alabama, Nevada, and British Columbia Georgian { Red sandrock, shales, and limestones; Shales and quartzites. Appalachian Range
	Eozoic	Algonkian	LAKE SUPERIOR AREA Keweenawan Upper Huronian Lower Huronian GRAND CAÑON AREA Chuar Grand Cañon Vishnu
		Arch-ean	Archean

Eozoic Era

The oldest rocks are classified in the Eozoic Era, which has two separate and distinct periods, known as the Archean and Algonkian.

Archean. The Archean rocks, or the basal complex, are highly folded and metamorphosed, containing secondary structures, being time and again intruded by still older plutonic rocks.

Algonkian. Algonkian rocks are also extensively folded, metamorphosed and intruded to a large extent, the difference between the Algonkian and Archean rocks is largely due to the possibility of arranging the Algonkian rocks with respect to well-known stratigraphic methods. The presence of sedimentary deposits are known in the Algonkian. No distinct animal or plant remains are found in the Archean and but rather few fossils have been found in the Algonkian, but not enough to warrant any attempt to subdivide the Era on the basis of remains that might indicate the presence of "life" in the system. A great unconformity exists between the two systems, strongly marked by basal conglomerates. The Era as a whole forms the foundation upon which all other rocks rest and no doubt from which they were derived.

The general nature of the Eozoic proves it to be unsuitable for oil and gas, mainly on account of the highly metamorphosed condition of the rocks. The Era is often referred to as the Pre-Cambrian.

Paleozoic Era

The oldest fossil-bearing sedimentary rocks are in the Paleozoic Era, or the Era of Ancient Life. The subdivisions of this group from the oldest upward are: the Cambrian, Ordovician, Silurian, Devonian and Carboniferous. In the beginning of this Era life was of the lower order and sea-weeds predominated; towards the close, however, we have a rather high order in the amphibians, or land and water animals. A high order of vegetation prevailed at the close of the Paleozoic. Most of the rocks are of marine origin, although fresh-water and swamp deposits are

also known. In general, the rocks appear to have been deposited mostly in shallow water. The beginning and end of the Era is well marked by unconformities caused by great disturbances of the Earth's crust.

Cambrian. The first appearance of trilobites was in the Cambrian, and due to the fact that three different members are characteristic of the system, the zones in which they are found have been correspondingly named, viz.: *Olenellus* or Georgian Group (Lower Cambrian), *Paradoxides* or Acadian (Middle Cambrian), and *Dikellocephalus* or Potsdam Group, (Upper Cambrian). There are also in the Lower Cambrian indistinct remains of sea-weeds, a few sponges, graptolites and corals and some very small pteropods (foot-winged mollusks, or brachiopods). Articulates, tracks and ripple marks are found in the Potsdam, which are indications of shallow water deposition.

The Cambrian so far has not been a producing horizon for oil and gas and it does not seem likely that it will ever prove to be of any importance. However, as only a small portion of the Cambrian is accessible for prospecting, as most formations of this period lie at great depths and the present methods of drilling are inadequate to reach these horizons, the Cambrian cannot be said to have been properly tested.

Ordovician. The whole of this system may be placed in a period before any vertebrate life came on earth, and the system is characterized by the large number of shells and corals that were developed during this time. Bryozoa, not found in the Cambrian, are abundant in this period. The Trilobites of this period have a much larger tail shield and can roll themselves up; and have rounder and better developed faceted eyes. Early Ordovician rocks show evidence of being formed in shallow water, with upheavals towards the close. A subsequent formation of limestones, and the thickening of the formations to the east would indicate that the upheaval was followed by subsidence. The Ordovician is noted for the culmination of the graptolites and they are the most characteristic fossils of this system.

The Ordovician has not been a great producer of oil and gas,

the Trenton Limestone fields of Ohio-Indiana are the only extensive pools known in it. A small amount of gas with a little oil has been found in the St. Peter sandstone, below the Trenton. The Trenton production is found where the limestone takes a dolomitic form.

Silurian. The Silurian period commenced with a submergence, when large limestone beds were formed, with thickening of the strata towards the east. The subsequent formation of the Salina beds would indicate another upheaval, during which the salt beds were formed in shallow water. A few fish appear in the Silurian, although corals still predominate. Crinoids make their first appearance. The chain coral *Halysites* is characteristic of the period. On the whole, we have a great marine period until towards the close, when marine conditions have been gradually replaced by continental conditions, shales passing into sandstones.

The oil and gas of the Silurian seems to be restricted to the Medina formation; the "Clinton" sand fields of Ohio and Ontario are of this age, and are believed to be part of the Medina sandstone rather than a continuation of the Clinton limestone. The gas so far seems to have exceeded the amount of oil that has been produced, although valuable discoveries of more oil are being constantly made. On the whole the Silurian has not been an extensive oil- or gas-producing age.

Devonian. The rocks of this period show that there was a considerable raising and lowering of the surface so that at one time the land was above water and at another time below. It was a great volcanic period and during it the earth's crust was disturbed by one of the greatest epochs of mountain formation. The seas were full of invertebrate forms similar to the Silurian's, although the Cystoids were almost extinct. Trilobites were fewer and had a characteristic ornamentation of the margin of the head as well as extraordinary development of spines which many display on the head and tail shield. Corals and brachiopods were in large numbers and new form of cephalopods appeared. Vertebrates, such as fishes, were well developed, and hence the Devonian is sometimes called the Age of Fishes.

The Devonian is one of the greatest gas-producing periods, and the upper half of it has considerable oil production in the Appalachian fields.

Carboniferous. The last period of the Paleozoic is divided into three subdivisions, which make up the entire Carboniferous; they are the Mississippian, Pennsylvanian and Permian.

The Mississippian system as a whole shows signs that the vegetation of the Carboniferous has been on a high plane. The presence of coal beds are first noted and they had been formed from the immense vegetation. Amphibians or lung and gill animals, that could live in water or on land make their first appearance, and they gave rise to reptiles towards the close of the period. Shales and sandstones form a great part of the Mississippian, but at the close of the epoch the formation of an extensive limestone is noted, generally referred to as the sub-carboniferous limestone, although different parts of it, as they make their appearance in various places in the country, are grouped and known under different names. During this period trilobites are still found, but become entirely extinct at the end of the Paleozoic. *Phillipsia* is a rare but characteristic trilobite of this age. A wide spread upheaval is noted at the close of the Mississippian. Cystoids disappear entirely in the Carboniferous, while Blastoids are abundant and characteristic of the Carboniferous limestones; Crinoids culminate their development while the Bryozoa *Archimedes* is characteristic of the Lower Carboniferous.

The gas production of the Mississippian is almost equal to the production in the Devonian, and the oil production has doubled that of the Devonian.

The Pennsylvanian is known as the Coal Age, as the best coal deposits are known to have been formed during this period. A generalized section of the Pennsylvanian shows that it is composed mainly of alternate layers of shales, sandstones, limestones and coal deposits. A great amount of oil and gas has been produced from rocks of this period, and the combined volume of the Mississippian and Pennsylvanian is exceeded only by the Tertiary deposits of foreign countries.

The Permian is not well developed in this country, and it really marks the transitory period between the Paleozoic and Mesozoic times. The division point between these two great ages is marked by great continental changes. The Appalachian uplift of the Eastern part of the country and the upheaval of the Utah Basin region as well as the submergence of the Nevada Basin were the characteristics of the Permian.

In this country the Permian has been found nearly barren of oil and gas, although a small amount has been found in the lower part of it. Most of the Permian is composed of depositions formed under semi-arid conditions (continental deposits), and as such are generally wanting in organic remains, they are not favorable for oil and gas.

Mesozoic Era

The Mesozoic Era may be described briefly as the Age of Reptiles. Two subdivisions are made, namely the Jura-Trias and the Cretaceous. This Era is noteworthy for the extensive eruptions at the close of the period.

Jura-Trias. A striking contrast is had between the beginning of the Jura-Trias and the close of the Paleozoic; the latter with its numerous upheavals seems to have settled down to a long period of gentle geographical change in the Jurassic. The Triassic has yielded the first known mammals, although they were not very flourishing in the Mesozoic. *Archeopteryx*, the first known bird, made its appearance in the Jura-Trias. The close of the Jura-Trias was marked by numerous upheavals.

The oil and gas possibilities of this epoch, as well as the lower half of the next one (Cretaceous), are similar to the Permian, and so far as the United States are concerned, very little may be expected of them.

Cretaceous. The formation of many chalk deposits gave the name to this period; in it some of the largest reptiles have been found and many well-preserved specimens have been obtained. The deposits of the Cretaceous are somewhat limited in the eastern part of the country, but are well developed in the west; in it we find many fresh-water limestones and lignite deposits.

The upper part of the Cretaceous has produced gas and oil, the main producing areas being Caddo, La., Colorado, Wyoming, Dakota and the Calgary, Alberta fields.

Cenozoic Era

The most recent subdivision of the geological column is known as the Cenozoic Era, and deals with "Recent Life," or the age of Mammals and Man. The Cenozoic is divided into two great periods, the Tertiary and Quaternary. They are further subdivided into Eocene, Miocene and Pliocene for the Tertiary, and Pleistocene (Glacial) and Holocene periods for the Quaternary.

A large amount of oil in the United States is obtained from the Tertiary and the total production is exceeded slightly only by the combined production of the Mississippian and Pennsylvanian. With the exception of the Mexican Cretaceous oil, all the foreign production is from the Tertiary. Tertiary oils are found mainly in unconsolidated sands, which yield enormous quantities of oil owing to the unconsolidated nature of the sand grains, which therefore have a large percentage of effective porosity.

CHAPTER IV

ACCUMULATIONS OF OIL AND GAS

THAT a commercial accumulation of oil and gas may be possible several requirements must be fulfilled. We must have a porous rock such as a sandstone, either the consolidated or unconsolidated type, or a suitable form of limestone to act as a reservoir. These rocks by virtue of their porosity may contain

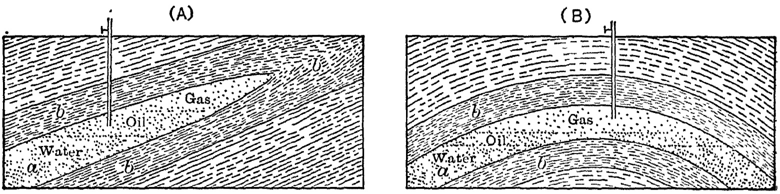


FIG. 10.—Types of Oil and Gas Reservoirs.

A, inclined bed of sandstone (*a*) sealed in by shales (*b*), but somewhere in communication with water under hydrostatic pressure. *B*, sandstone bed (*a*) interstratified with impervious beds (*b*) and forming an arch or anticline, somewhere in communication with water under hydrostatic pressure. (U. S. G. S. Bulletin 429.)

and accumulate oil and gas provided they are sealed in so that their contents may not be lost by migration or evaporation. Shales play a very important part in this connection, as they act as an impervious seal, and when such a shale body entirely envelops the entire porous reservoir, then accumulations may become possible. A lenticular sandbody is a familiar example of this type, and serves as the reservoir, while the shales form a seal. (Figs. 10*a* and 11.)

As the porosity of a rock is variable, so that portions of it may be very porous and other parts less so, naturally the most porous portion will be the most suitable for oil and gas accumulations, while the non-porous, or less porous portion will act as a

seal. A condition of this kind is due to the differential cementation of the sands, and the oil man speaks of the non-porous sand as a tight sand, while the porous one is called an open sand.

Accumulations that are controlled by the porous portion of a sand body are similar in shape to accumulations found in lenticular sands, and are also known as lenticular pools, but in such a case the lenticular form refers to the shape of the "Pay" portions of the formation as the entire sand body itself may not be lenticular. From this we may infer that if the central part of a formation has an effective porosity sufficient for commercial accumulations, the surrounding less porous part may act as a seal.

The term "sand" is employed by the practical oil man to

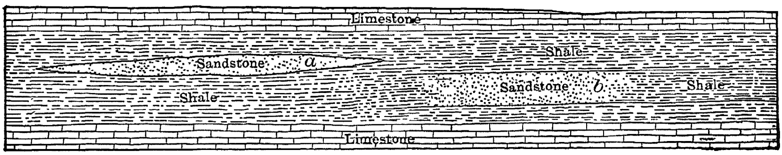


FIG. 11.—Sketch Illustrating Disappearance of Sandstone Beds.

a, lenticular sandstone which disappears by thinning out; *b*, sandstone which grades into shale. (U. S. G. S. Bulletin 429.) The "Clinton" sand production of Ohio is found in such lenticular reservoirs.

indicate the producing horizon regardless of its actual texture; thus it may be a sandstone, limestone or shale, but if producing oil or gas it is called a sand. In this connection sand will be used to indicate a sandstone formation only.

Quite often the rocks in which the accumulations are expected, come to the surface (crop out); the examination of such outcrops will generally show signs of petroleum, but as the outcropping permits the escape of the oil from the rock, such a rock will therefore be less important at the point of outcrop than it will be some distance under cover. The escaping oil, however, may form a seal upon evaporation at the outcrop, and permit accumulations a short distance away. There are many instances where oil pools are found close to the outcrop of the sand, but such pools are generally short lived. However, this disadvantage

is overcome by the fact that the pools are shallow and may be operated at a comparatively small expense.

Considering the case of a reservoir that is uniformly porous and where oil and gas may migrate great distances, the presence of a fault or intrusive may act as a seal. A fault may bring a comparatively non-porous rock into juxtaposition with the sand or the faulting action may form a gouge which acts as a cement and fill up the affected portion of the sand body. Often a fault

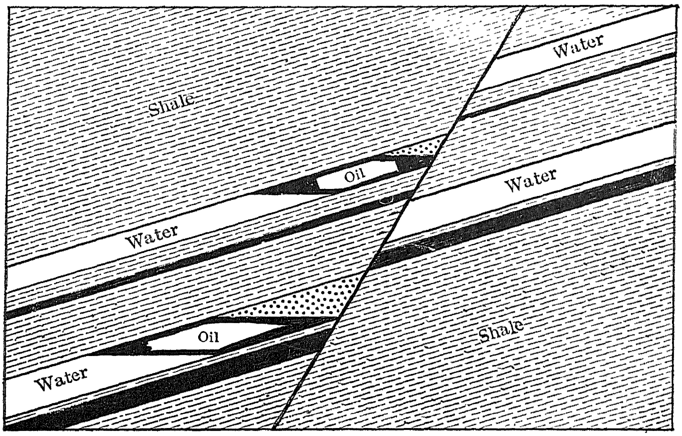


FIG. 12.—Showing Gas and Oil Accumulations made Possible by Faulting, where the faulting action brings an impervious strata in juxtaposition with an oil sand, forming a barrier to further migration, the gas and oil accumulating below the fault plane, and above the water in the sand.

or an extrusive permits the escape of oil and gas from the sand to the surface. (Fig. 12.)

Accumulations of a large amount of oil and gas have been made possible by the presence of a suitable geological structure; in other words, where the strata have been folded, and the sand is filled with gas, oil and water, the folding permits the separation of the gas, oil and water according to their specific gravities, and if the sand is porous throughout, the accumulations of gas will be found at the highest point of the structure, the oil above the water level, the water in the lower parts. In the absence of water, the oil may be expected in the lower portion of the

structure. These folds or geological structures may be various kinds, such as anticlines, homoclines, synclines or some variation of them. As these structures are often evident from the surface they are of great importance in locating promising oil and gas territories. (Figs. 10*b* and 13.)

The porosity of the rocks is one of the main controlling factors. The larger the pore space the greater the possibility of the movement that may take place in it. The porosity of a rock

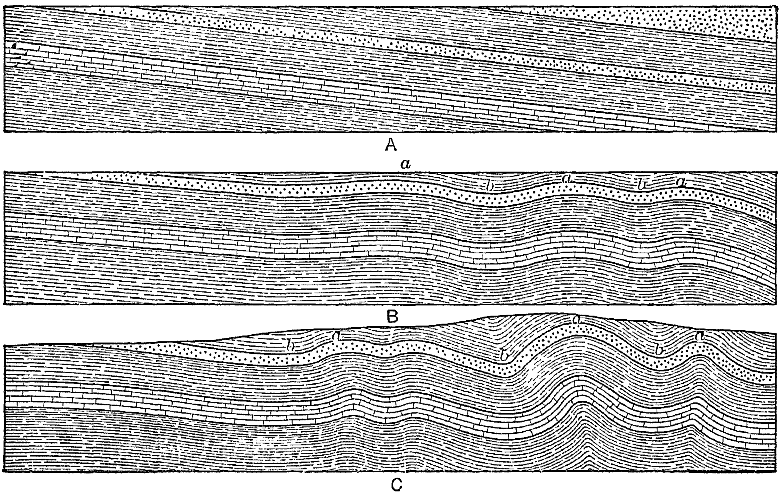


FIG. 13.—Simple Types of Structure.

A, sedimentary beds with gentle dip; *B*, the same beds gently folded; *C*, the same beds more intensely folded; *a*, anticline; *b*, syncline. (U. S. G. S. Bulletin 661–F.)

specimen is determined by the amount of water it will absorb as shown by the weight of the rock before and after saturation. The figure so obtained will represent the *theoretical porosity* of the specimen, which may vary from 5 to 40 per cent. The most porous sands are those that are made up of grains of uniform size, thus a sandstone whose grains are of different sizes, the smaller grains may fill the spaces between the larger ones, naturally reducing the size of the pore space. The question of porosity is discussed by R. H. Johnson* as follows: "Pores are

* Transactions of the American Institute of Mining Engineers, Vol. LI, p. 648.

of two kinds: Those which are entirely inclosed, so that they do not belong to a system of communicating pores tapped by the bore hole or shot hole; second, those which do so communicate. Porosity, of course, includes both. But since pores of the first class are valueless to us, we should confine our attention to the latter, for which I propose the term 'effective porosity.' " Various calculations have shown that the maximum effective porosity of an oil sand of the consolidated type is 6 per cent of the whole, and in many fields it is much less. Only a portion of the actual amount of oil in a sand is obtained with the present producing methods. All the oil is not recovered because the movement of oil from the pores of the sand into the bore hole is caused by the pressure of the gas with the oil, and when this pressure has declined the flow of oil is stopped and the wells production becomes so small as to be no further profitable. So it will be seen that although a well may be abandoned as no longer a commercial venture, still there may be a great amount of oil in the sand that has not been recovered. The question of porosity is becoming more and more important as the known fields are depleted, and further recovery of oil is made possible by flooding the sand or by artificial restoration of the lost "rock pressure," in order that recovery may be increased.

Porosity is of great importance in calculating the volume of oil in the sand, as by means of it a valuable approximation may be made as to the value of a field or property. Even in cases where decline curves are used in such valuation, the porosity should also be considered and the two methods used together.

Oil and gas might have been formed in the sand where they are found or again might have originated in the nearby strata and have migrated into the sand body. The common conception is that the oil has migrated into the sand body, however, a few are of the opinion that it has originated in the sand. That movements of oil and gas are possible are due to several factors. The weight of the overlying sediments will cause compacting and force the contents of a stratum out, through the road of least resistance, into the sandstones as they offer better chances for accumulations. The constantly increasing pressure of the over-

lying rocks due to further sedimentation may be one of the factors of motion (Fig. 14) as well as many others, such as the increasing temperature at greater depths, the formation and pressure of newly formed gases (dynamo chemical gases),* the effect of capillary attraction in the pores, hydrostatic pressure, the specific gravity of oil and water, and earth movements (diastrophism). One or a combination of these factors may cause migration. As to compacting, sandstones and limestones offer greater resistance than shales, therefore they are not so easily and firmly compacted, allowing for greater pore space.

The pressure of gases may be said to depend on various factors, and some of those that will cause migration may also

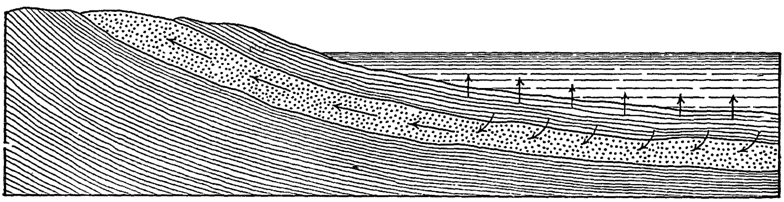


FIG. 14.—Diagrammatic Section Showing the Flow of Connate Water and Gas Due to Compacting of the Sediments.

(After King, U. S. G. S., 19th Ann. Rpt., Pt. 2, p. 80.)

produce or increase pressure. Thus, the formation of new gases will exert a certain amount of additional pressure, as well as the closing up of the pore-space due to compacting, or the addition of more cement, which will reduce the size of the spaces, compelling the same volume of gas to occupy less space. The weight of the overlying strata exert pressure and hydrostatic pressure no doubt plays an important part in this connection.

Many, if not all these factors are required to explain pressure, and as most of these are not obtainable, to calculate possible pressure, only such methods are used that have been obtained from the study of actual conditions in the field, based mainly on the figures obtained from pressure readings, and those figures form the basis of the formulæ that are in use. Only an approxi-

* Johnson and Huntley, "Principles of Oil and Gas Production," pp. 46 and 52.

mate calculation is possible, and as it has been found that pressure and depth seem to have some relation to each other, this has been used for calculating pressure. The possible pressure may be approximated by multiplying the calculated depth of the sand from the average altitude by the weight of a column of water one square inch at the base, one foot in height, plus the addition of a constant. This constant can be determined only after a field has been partially developed, or the constant of a near-by pool may be used. The weight of a column of pure water as above mentioned is .43 pound, and that of salt water more, in some fields a weight of .57 has been found. A formula of Dr. Edward Orton, worked out for the Trenton fields of Ohio, uses .48 for the weight of this column of water, and his constant is .41 thus his formula may be expressed as follows:

$$\text{Pressure} = 0.48 \times \text{depth from average altitude} + 41.$$

Methods like the above will give results that will be sufficient for most purposes, but they only apply to the original pressure in the reservoir; after the pool is drawn upon the pressure becomes less.

CHAPTER V

STRUCTURE

THE various deformations of the strata that are considered as favorable mediums for the accumulation of oil and gas are known as structures by the oil man and geologist. The various structures that have more or less bearing on the accumulation and location of wells are the anticlines, synclines, noses, terraces, embayments and homoclines. These are the most familiar ones encountered in producing fields; however, faults, intrusions, extrusions and unconformities may also bring about or affect production in various ways.

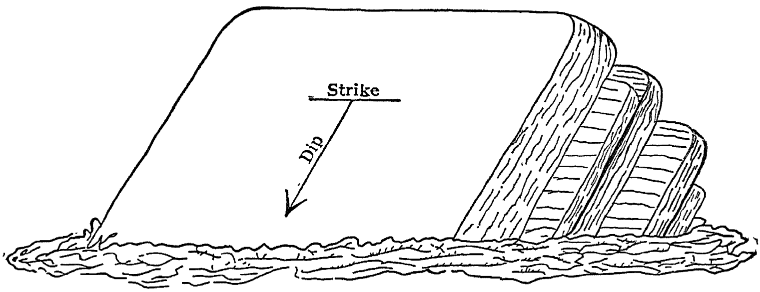


FIG. 15.—Outcrop of Inclined Strata, Showing Direction of Dip and Strike.

The study of these attitudes or structures belong to stratigraphic and structural geology, and are based on the determination of the various dips.

Dip and Strike. Rocks that have been tilted in various ways are said to be dipping, the dip being the degree of inclination that a rock makes with the horizontal. The course of a stratum in a horizontal plane is known as the strike, and it will be at right angles with the dip. (Fig. 15.) The deviation from the hori-

zontal may be from a fraction of a degree to the vertical. Mountains are generally formed by large dips; the smaller undulating dips may or may not find expression in the surface.

Large dips are determined with a clinometer placed along the line of the dip, which is the direction in which water would flow down along the exposed surface of a true dip; the reading is taken in degrees and the direction noted by magnetic bearings. Such readings are represented on a map by the use of an arrow or dip sign. The arrow points in the direction of the dip, and the angle of dip written along the line of the arrow. The direction of the strike is shown by the line drawn perpendicular at the end of the arrow. In regions of small dips or few exposures it is necessary to find the elevation of the outcrops of a key-horizon above a datum plane; this may be done with an aneroid barometer, engineer's spirit level, transit stadia or plane table. The elevations so obtained enable the preparation of a structure contour or *isobath* map, which will be a graphical representation of the dips and strikes. Regional dip may be figured if the elevation of a stratum is determined at three points. The points should be preferably the points of a triangle, and not in the same straight line.

The dip of the strata may remain the same for great distances or may change from place to place, forming various folds. A dip in one general direction is known as a homocline. When two homoclines dip *AWAY* from a common line or axis, they form an anticline. In other words, an anticline is an upward fold of the strata forming an arch (convex side up).

Two homoclines dipping *TOWARDS* an axis form a syncline or trough (convex side down).

Anticlines may be various kinds, such as a dome, level top or level axis and plunging anticlines.

Dome. When the strata dip away in all directions from a central point they form a dome.

Level Top or Level Axis Anticline. If the axis, or the line from which the strata dip away, is level for a distance, it is known as a level top or level axis anticline.

Plunging Anticline. When the anticlinal axis itself dips

in a certain direction, the anticline is known as a plunging one.

Anticlinal Nose. A smaller and generally a plunging anticline along the flank of a main anticline (or along a homocline), is called an anticlinal nose.

Terrace. A sudden flattening of the dip for a short distance, forming a step like structure is a terrace.

Syncline. As previously explained a syncline is the opposite or complement of an anticline; similarly the complements of a dome is a basin; of a level top anticline it is a level axis syncline;

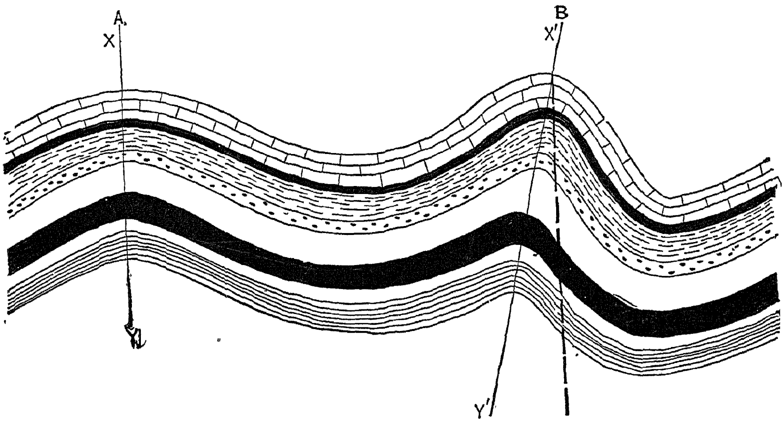


FIG. 16.

A, symmetrical anticline; *B*, asymmetrical anticline; *X–Y*, *X′–Y′*, axial plane. In asymmetrical anticlines, the angle formed by the horizontal and the axial plane is the dip, and the angle formed by the vertical and the axial plane is the hade.

and thus we have the plunging syncline, as well as the embayment which bears the same relation to a syncline that a nose does to an anticline.

Asymmetry. Anticlines and synclines are said to be asymmetrical (un-symmetrical) when the dip on one side of the axis is greater than the dip on the other side. (Fig. 16.)

Faults. The different stresses at work affect seriously not only the shape of the strata, but sometimes exert such pressure or force upon them as will cause a fracture or break, accompanied by displacement of one side of the strata with respect to

the other, along a line, or a shear zone, thus forming a slip or fault. Faults may be due to either lateral pressure (crushing force) or may be produced by tension (pulling apart). The resulting faults may have different characteristics; the former causing thrust and reverse faults, the latter normal faults. The side which has been pushed up over the other is the hanging-wall, or as most commonly called, the up-throw, the under side being the foot wall or down-throw. The distance of such throws may be anywhere from a few inches to several hundred feet.

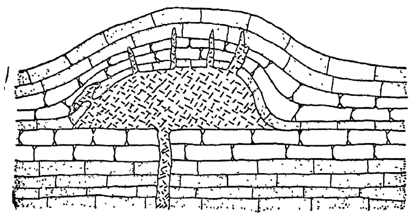


FIG. 17.—Intrusive, Forming a Laccolite.

The heave of a fault is the horizontal distance of displacement; the hade is the angle of the fault line or shear zone with respect to a vertical plane.

Intrusives. Igneous rocks forced up into sedimentary rocks are known as intrusives. They may, when cooling, cause a dragging of the broken edges of the sedimentary beds, forming a sort of an anticlinal structure, in which oil or gas may accumulate.* (Fig. 17.)

* V. R. Garfias and H. J. Hawley, Funnel and Anticlinal-ring Structure Associated with Igneous Intrusions in the Mexican Oil Fields. Bulletin 128, American Institute of Mining Engineers.

CHAPTER VI

THE EFFECT OF STRUCTURE UPON ACCUMULATIONS

THE value of a structure for commercial accumulations depends upon the effective porosity and the extent of a sand body, in which gravitational separation may take place. It is a well-known fact that gas, oil and water if placed in a closed vessel, will arrange themselves in order of their specific gravities; thus water will occupy the lowest parts of the vessel, the oil above it and the gas occupy the upper portion. This same gravitational separation will take place in a porous sand body. If the pores are intercommunicating and the reservoir is continuous to any extent, large accumulations become possible under favorable structure, the controlling effect and importance of which will be evident.

Dome. It will be apparent that the gases will occupy the highest portion of domes, with oil under them, resting upon the water that will be accumulated in the lower portion of the structure (or in the syncline). The degree of saturation of a dome depends upon the amount of water in the syncline and the extent of the oil above it. If the amount of gas and oil are greater than could find lodgment in the dome they will flow or "spill" into adjoining structures, finding their way into them along the spilling lines. (Fig. 18.) The spilling point of a dome is immediately below the lowest closed contour line. The general nature of a dome stamps it as a very desirable structure for prospecting, especially suitable for gas accumulations, and for oil as well in the absence of a large amount of gas.

Level Axis Anticline. A level axis anticline is the next favorable structure to a dome; they are more frequently found than are the domes, and have proven to be of great value in accumulation of oil and gas in different parts of the country.

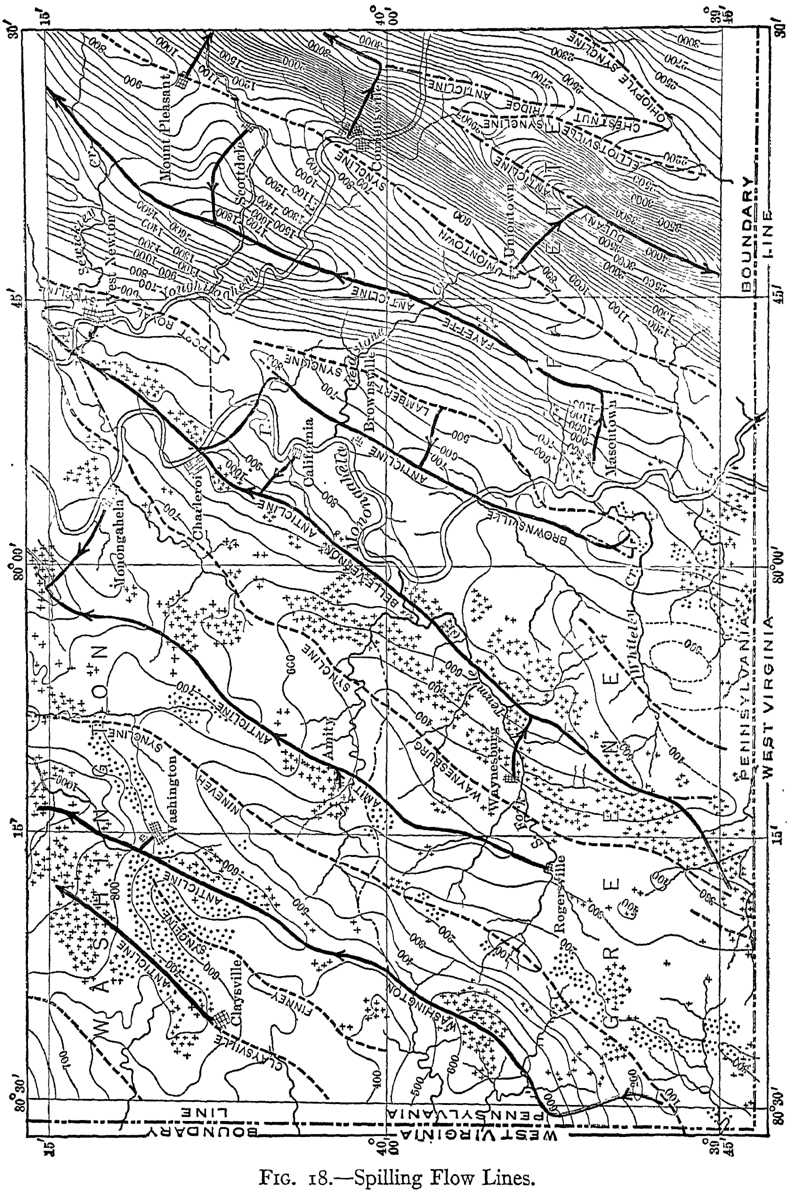


Fig. 18.—Spilling Flow Lines.

Heavy lines are paths in a sheet sand that gas would take if unobstructed and if there was enough gas to fill the domes. Several arbitrary starting points were chosen. (Drawn on map from U. S. G. S. Bull. 456.) (Johnson and Huntley.)

The spilling point for a structure of this kind will be at the point where the major or minor axis crosses the lowest closed contour line.

Plunging Anticline. The value of an anticline is greatly diminished if its axis is a plunging one, as the plunge might bring the most favorable portions of the structure to a point where the reservoir rock has been exposed and eroded. The size of the plunge may have varying effect; the structure may be of value if the height of the water level in the sand is known; but, in general, it is of no greater value than are plane dipping homoclines.

Nose. Noses are most commonly found along the axes of plunging anticlines, and as such are important in increasing the value of such a plunging anticline. They also occur along homoclines, where they are equally important.

Embayment. These may become important in connection with the spilling line, in the absence of water at the height (or above) this structure.

Homocline. Homoclines, in general, are in great disfavor among prospectors, as accumulations along such structures are due mainly to the lensing or differential cementation of the sand. As these conditions cannot be known from the surface a homocline offers less chance for prediction; and it is risky to condemn a property merely for the lack of better structure, but of course, on the other hand, they are not as favorable prospects as are the more suitable structures. Homoclinal production, if examined, will show that it is in accord with the structural theory, in so far as the gas, oil and water is concerned, for that particular sand. In the "Clinton" sand homoclinal accumulations of Ohio it will be noticed that the gas and oil will be found in their relative position along the dip of the rocks, and the main course of production follows very closely the strike of the rocks. A knowledge of the lateral variation of the strata is very important in homoclinal fields.

Terrace. In places where complete saturation exists a terrace may be considered as worth while for prospecting for oil. Small terraces in surface structure cannot be depended upon as well as

larger and well defined ones. A consistent and well-marked lateral variation of the strata may easily obliterate surface structural evidences and especially in case of terrace structure it may not show in the sub-surface structure at all.

Fault. The presence of faults should be carefully studied as they may seriously effect accumulations. The faulting action may form a gouge which may serve as a seal, permitting accumulations in the stratum lying on the down-dip side, or again, the throw may bring an impervious stratum in juxtaposition with the oil bearing one, and permit accumulations in it. (Fig. 12.) Faults may permit the migration of oil and gas to a higher sand, and again may permit their escape and loss at the surface; thus, seepage along a fault may indicate that the reservoir has been broken into and its contents lost. Large faults are in most cases dangerous.

Intrusives and Extrusives. The effect of intrusives and extrusives may be similar to the action of faults; there is also a possibility of accumulation in the anticlinal ring formed during the shrinkage of the foreign material. They are to be carefully guarded against, as in most cases their presence is unfavorable.

Unconformities. In a few instances oil and gas have been found in connection with unconformities. A case of such accumulation is known in the Potsdam sandstone; the Potsdam having been eroded into hills and valleys and subsequent deposition formed impervious cap-rock under which the gas has accumulated; especially in those parts which the erosion left as hills. A similar case is known to exist in the Berea sand in Ohio, where the strata have been eroded by glacial action and parts of the Berea being eroded, the subsequent deposition of glacial drift has obliterated the former valleys formed by the glaciers, and formed a barrier permitting accumulations in the Berea, where it has not been eroded. Unconformities may be so located that they act as barriers similarly to faults.

CHAPTER VII

SURVEYING INSTRUMENTS AND METHODS

THE maps used in the every-day work of the oil man are constructed by various surveying methods. The information desired is obtained by the measurements of horizontal and vertical distances and angles. These may be obtained by one or a combination of several methods. The measurements of horizontal distances may be done either by pacing, graduated tape or chain or by stadia methods. For vertical measurements we have the aneroid barometer, engineer's spirit level and stadia methods.

Two of the above mentioned methods may be easily learned and put to practical use. They are pacing, for the measurement of horizontal distances and the use of the aneroid barometer for determining vertical distances or elevations.

Pacing Survey. The method of determining horizontal distances by means of the stride or pace is known as pacing. Distances so obtained are approximate, but quite often such results are of great value.

To determine the pace the following procedure is recommended: measure out carefully a distance of several hundred feet on level ground, then starting at one end walk along this measured line towards the other end, using NATURAL steps, and counting them. From the figures so obtained the NATURAL step or stride may be calculated, for example:

Distance measured $= 500$ ft. $= 6000$ inches
Number of steps taken $= 200$
$6000 \div 200 = 30$, or thirty inches ($2\frac{1}{2}$ feet), per stride.

When the measurement of any distance is required it simply necessitates walking over the distance, counting the number of

steps taken and multiplied by the constant for each step, which will give the desired result.

Attention is called to a system in use by great many people, which necessitates the "stepping off" a certain distance, such as three feet for each stride. Any attempt to regulate the step to three feet will bring about poor results, as it requires unnatural walking. Sometimes it is also desirable that when a distance is paced that it should not be observed by anyone present, so if natural steps are taken such a purpose will not be disclosed.

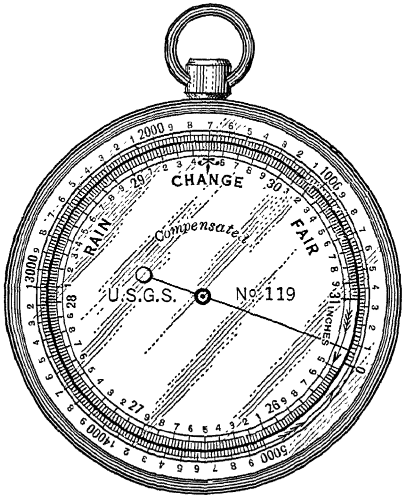


FIG. 19.—Aneroid Barometer.

By using natural steps one may cover good distances with less effort and without the tiresome results of awkward walking, and obtain better results.

Experiments should be made with fast walking, pacing over rough and hilly ground as well as through tall grass. It will take but a short time and one accustomed to pacing will obtain good results.

By the use of this method it is possible to determine the location of wells on a neighboring farm; one needs but to walk from the well at right angles to the nearest property line and the distance obtained will be correct to within a few feet. Pacing

may be used for many practical purposes where exact figures are not needed.

Aneroid Barometer. The aneroid barometer is a handy and very useful instrument for the oil man, and by careful handling, elevations may be obtained and such knowledge used for practical purposes. (Fig. 19.) By use of it, it is possible to determine the elevation between wells, and calculate the amount of casing needed. It will also enable the calculation of the dip of the sand, and may be used to determine the elevation of surface outcrops. Unfortunately many speak unfavorably of the aneroid, but the instrument if carefully handled may be used with sufficient accuracy and speed, which may become very desirable in many instances.

The aneroid barometer is an instrument that shows the pressure of the atmosphere, and a good sensitive instrument will show the variation of pressure due to the difference in height of a few feet.

The weight of a column of air surrounding the earth may be likened to the weight of a number of books piled in order, and resting on one's hand; the greater the number of books, the higher the column and greater the pressure on the hand. Similarly with air pressure, the column of air above a mountain will be less than the column of air over the adjoining valley. The aneroid is the instrument that measures this column of air, or atmospheric or barometric pressure. Such a pressure is most commonly measured with a mercurial barometer, but as it is not so easily carried around due to its size, the aneroid barometer is used which is compact and less fragile. The weight of the column of air acts upon an elastic top of an exhausted (vacuum) metallic box, and the pressure is magnified by means of a lever and shown by a dial or hand on a scale graduated to show elevations.

It must be remembered that the atmospheric pressure is liable to certain variations, and for this reason the dial of the aneroid will sometimes move when the instrument is stationary, indicating changes in atmospheric pressure. The atmospheric changes must be taken into consideration and corrected when the instrument is used for obtaining elevations.

The aneroid should be carried in the vest pocket at all times, to keep the temperature of the instrument constant. If the instrument is too large for the vest pocket it should be carried in the case with which all such instruments are provided. The work generally starts at a certain bench mark or at an assumed one.

Supposing that the elevations at the top or well mouth of three wells are wanted, the procedure is as follows: Starting at a bench mark whose elevation is assumed to be 1000 feet above sea-level, the barometer may either be adjusted so that the indicator will point to 1000 feet or left as it is and the difference noted. It is best not to change the indicating hand, as the act of changing the position of the needle may unsettle the instrument for the time being.

Standing at the bench mark with instrument in hand and holding same face up, the aneroid is tapped gently to allow the needle to be loosened to avoid "lagging"; care must be taken not to press the bottom of the instrument, as such pressure will be indicated by the needle. The needle reads 1120 feet at the bench mark which is 1000. Record this reading in the note book as well as the time of the observation, which is assumed to be 9:30 A.M. From the bench mark go to the first well and repeating the method used at the bench mark, reading 1260 feet at 9:40. At the second well the readings are 1200 feet at 9:50 and at the third and last well 1100 feet at 10:00 A.M. The next step is to go back to the original bench mark (or to any other bench mark that may be nearer), and the readings taken again, the instrument reads 1140 feet at 10:30 at the bench mark. It will be noticed that the readings at the same bench with the same instrument at two different times shows a difference of 20 feet; which is due to the change in the atmospheric conditions in the interval. This difference is to be corrected for as follows: The error is $+20$ feet and the time interval one hour (60 minutes). The time interval divided by the error $60 \div 20 = 3$, which is the number of minutes for each foot of change, i.e., for every three minutes the atmospheric change was one foot. Ten minutes after leaving the B.M. at the first well the error will

be $10 \div 3 = 3\frac{1}{3}$, which is to be subtracted from the reading at that point, which will be $1260 - 3\frac{1}{3} = 1256\frac{2}{3}$. The second well reading taken at 9:50, or 20 minutes after leaving the B.M.; the reading at that point is to be diminished by $20 \div 3 = 6\frac{2}{3}$; the corrected reading will be $1200 - 6\frac{2}{3} = 1193\frac{1}{3}$ feet. The third reading taken thirty minutes after leaving the B.M., the correction at that point will be $30 \div 3 = 10$, hence $1100 - 10 = 1090$. The errors are to be subtracted (as in the above case) when the check reading at the bench mark is higher than the first reading. If the check reading should be lower than the first reading the calculations are the same, but the error is to be added in each case.

The next procedure is to take into consideration that the instrument was not set to read the exact elevation. The B.M. was 1000 feet and the instrument read 1120 feet. The instrument reading being greater by 120 feet, this is to be subtracted from the corrected readings at each well, and the elevations so obtained will be the required elevation of each well. (Fig. 20.)

It must always be remembered that atmospheric changes will bring variations in the aneroid's movements, and therefore it must be constantly guarded against by checking at every opportunity at some bench mark. Every instrument has certain peculiarities with which the user must become acquainted. Some instruments have a certain amount of "lag," or in other words they do not catch up quickly with the change in elevation. This can be determined by several trials between two bench marks near each other and at different altitudes. A word of caution regarding the tapping of the instrument; a stiff needle will stand a great amount of tapping, but a sensitive one will respond very quickly, but unfortunately each tap will bring about different readings, so the best instrument is one that has a needle that is neither too sensitive nor too stiff.

Large field parties note the change in atmospheric pressure on a barograph or a recording barometer which is left in the office, the changes as noted by it being used in figuring the errors due to such changes, or as a check on recordings as figured in the field.

Weather—Clear. L. S. P.

ANEROID SURVEY 8–20–'18.

Sta.	Reading.	Time.	Calculat.	Diff.	Elev.	
B. M. 1000	1120	9:30 A. M.	....	−120	....	B.M. N.E. Cor. R.R. bridge over river. Sec. 14.
Well No. 1	1260	9:40	$1256\frac{2}{3}$	−120	1136.66	A. Wills No. 1. Sec. 15.
Well No. 2	1200	9:50	$1193\frac{1}{3}$	−120	1073.33	A. Wills No. 2. Sec. 15.
Well No. 3	1100	10:00	1090	−120	970	A. Wills No. 3. Sec. 16.
B.M. 1000	1140	10:30	....	....	....	B.M. as above. Sec. 14.

Calculation.

B.M. 1120 at 9:30.

B.M. 1140 at 10:30.

Diff. 20′ in 60 minutes.

1 ft. change for every 3 minutes.

$10 \text{ minutes} = 3\frac{1}{3}'$ $\quad 1260 - 3\frac{1}{3} = 1256\frac{2}{3}$

$20 \text{ minutes} = 6\frac{2}{3}'$ $\quad 1200 - 6\frac{2}{3} = 1193\frac{1}{3}$

$30 \text{ minutes} = 10'$ $\quad 1100 - 10 = 1090$

$60 \text{ minutes} = 20'$

FIG. 20.—Method of Keeping Aneroid Survey Notes and Calculations.

The rest of the surveying methods at our disposal are mainly the well-known surveying methods, which require a knowledge of surveying. The following paragraphs will not take up these methods in detail, but are intended merely as a grouping and a short review of the various systems in use by the oil and gas geologist.

Hand Level. The hand level, also called the Locke Level, is shown in Fig. 21. The bubble of the small level tube *C* can be seen through the opening *D*, by means of a reflecting prism. A cross hair placed in the main tube *AB* serves to fix the object observed, and when this hair bisects the reflection of the bubble, the line of sight is horizontal.

The height of the observer's eye, when he is standing erect, must be known. Thus if the height of the eye above the ground is five feet, the object observed through the hand level when it is

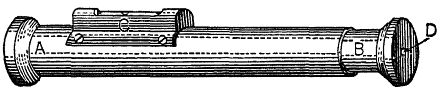


FIG. 21.—Locke Hand Level.

held horizontally, will be five feet higher than the point on which the observer is standing.

Clinometer. If a hand level is equipped with a movable spirit level and an attached vertical circle graduated to degrees, it is known as a clinometer. When the line of sight is given any inclination and the level turned to a horizontal position the angle of inclination is determined. A clinometer may also be used as a hand level if the bubble is set parallel (at zero degrees) to the main tube. (Fig. 22.)

Hand levels and clinometers are useful instruments in following outcrops from place to place in a country of low dips and few exposures. By standing at an outcrop on a hillside, the corresponding level on an adjoining hillside may be determined and another outcrop of the same formation looked for. Measuring vertical distances between strata may be done with a hand level rapidly. The angle of inclination or dip of a stratum may be found by the use of the clinometer.

Engineer's Spirit Level. Levels most commonly used in engineering work consist of a line of sight, attached to a bubble vial on a vertical axis which may be firmly attached to a standard or tripod. By means of leveling screws the bubble is brought to the center of the vial, making the line of sight level. The instrument is used to determine the difference in elevation between two or more points accurately. A rod, graduated to feet and tenths are used in conjunction with the level. The rod is held vertically on a point whose elevation is known (generally a B.M.) or is assumed, the level set up and the intersection of the line of sight on the rod is noted; this is known as the back-sight (B.S). Adding the back-sight to the elevation, the height of

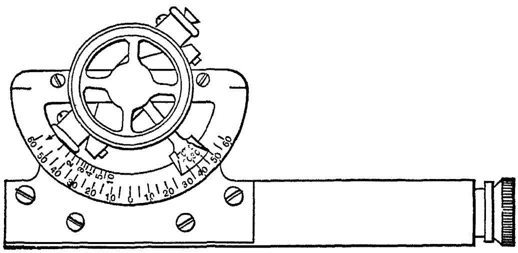


FIG. 22.—Abney Level and Clinometer.

instrument (H.I.) is determined. The rod is then placed on a point whose elevation is desired and the intersection of the line of sight on the rod is again noted. This operation is the fore-sight (F.S.). The elevation of this unknown point is calculated by subtracting the fore-sight from the height of instrument. Thus we have for determining elevations the following formulæ:

$$E + B.S. = H.I.$$

$$H.I. - F.S. = E$$

If the distance between two points is too great either vertically or horizontally or both, to admit of this simple process, two or more settings of the level are required so as to secure a connected series of rod readings, the algebraic sum of which gives the desired difference of elevation between the two points. (Fig. 23.)

LINE OF LEVELS

G. B. —Level.
Ashwell No. 1–2. Babcock No. 6. A. F.—Rod.
7–26–'18.

Sta.	B. S.	H. I.	F. S.	Int. S.	Elev.	
B.M.	1.54	739.64	....	....	738.10	U. S. G. S. B.M. 738.10. R.R. bridge. Sec. 7.
	8.40	743.26	4.78	....	734.86	
Well No. 1	....	....	....	4.56	738.70	G. Ashwell No. 1.
Well No. 2	....	....	....	0.78	742.48	G. Ashwell No. 2.
	.34	731.58	12.02	....	731.24	Stone ledge at property line.
Well No. 3	.68	720.45	11.81	....	719.77	J. Babcock No. 6.
	2.08	711.03	11.50	....	708.95	Public Highway.
B.M.	....	....	.06	....	710.97	B.M. at Rd.×711. Sec. 8.
Check......	13.04		40.17			
	40.17	F. S.	738.10			
	−13.04	B. S.	−710.97			
	27.13	⟷	27.13			

FIG. 23.—Spirit Level Notes.

Only one back-sight is taken from one set up of the instrument, but any number of fore-sights may be made; care must be taken in using any of these fore-sights for a turning point that the proper one be so recorded and the rest considered as extra or internal sights (I.S.).

Adjustment of Wye Level. Line of collimation adjustment is as follows: By means of tangent screw and leveling screw bring the intersection of the cross hairs upon a well defined and distant point. Revolve the telescope in the wyes one-half a revolution. If the intersection of the cross hair is still on the point sighted at, the line of sight coincides with the axis of collimation; if not, the adjustment is for one-half the apparent error which is done by moving the capstan-headed adjusting screws, being careful to move them in the opposite direction to which it would appear they should be moved. The apparent error shown by reversing the telescope is double the real error.

The second adjustment is to make the axis of the level tube bubble parallel to the axis of the collars, and, consequently, parallel to the line of collimation.

Level up the instrument over a set of leveling screws, open up the wye collars and *revolve* the telescope, first in one direction then in the other. If the instrument is in adjustment the bubble should stay in the center of the vial; if moving first towards one end and then to the other, the error is to be corrected by bringing the bubble nearly to the center by means of the capstan-headed adjusting screws at the end of the level tube, which regulate its lateral movement, and repeat the operation until the bubble will remain centered during the partial revolution of the telescope.

This will take care of the lateral adjustment; for the vertical adjustment proceed as follows: level up the instrument, and take the telescope out of the wyes and turn it end for end, if bubble remains in center, adjustment is correct, if not, bring bubble half way back by the adjusting nuts at one end of the tube and the remaining half by leveling screws.

The third adjustment, or wye adjustment, consists in leveling up the instrument, removing the telescope and turning it end for end in the wyes; if bubble is out, one-half the error is to be

corrected for by the adjusting nuts on one end of the wyes, the other half by leveling screws. Repeat the operation over the other set of leveling screws.

Sometimes an adjustment is made to make the cross hairs horizontal. It is horizontal if both ends as well as the center of the horizontal hair will cut any object sighted at, when the telescope is revolved on the vertical axis; if not, the reticule adjusting screws are to be loosened and the reticule to be rotated until the hair is horizontal.

THE TRANSIT

The engineer's transit consists of an alidade, carrying a line of sight, attached to an inner vertical circle (upper motion) which may be turned in an outer circle (lower motion). The lower motion carries a horizontal circle which is graduated to degrees that may be read to minutes by means of a vernier. The alidade includes the telescope and a magnetic needle with its graduated circle; it may be revolved while the graduated limb remains stationary. The instrument is supported by a tripod head by means of which it may be attached to a tripod. The complete transit should have a vertical circle graduated to degrees and vernier to minutes, and a level bubble attached to the telescope.

The transit is used for measuring horizontal and vertical angles. The attached bubble enables it to be used also as a level.

The telescope carries besides the regular cross hairs, equidistant from the horizontal one, two other horizontal cross hairs, known as stadia hairs. The object of the stadia cross hairs is the measuring of distances by reading an intercept on a graduated rod. In most instruments the stadia wires are so adjusted that an interval of one foot on the rod between the cross hairs will indicate that the point where the rod is held is 100 feet from the objective lens of the instrument, to this the instrument constant is to be added.

Horizontal as well as vertical distances may be determined by means of stadia wherever a great degree of accuracy is not required. The transit is set up over a station and the intercept on the rod is noted, as well as the angle shown by the vertical

L. S. P.
A. F. O. 8–7–'18.
J. J. D.

	Vert. A or B. S.	Stadia Interval or H. I.	Fig. from Table or F. S.	Interval × Fig.	Elev.	
					869.00	B.M. on bridge 869.00.
Stadia......	+9° 4′	731, 262 } 469	15.56	+72.98	941.98	
	−9° 32′	558, 442 } 116	16.33	−18.94	923.04	Ames Limestone (Top) 1′6″ thick. Fossils.
	+6° 21′	581, 424 } 157	10.99	+17.25	959.23	
	+4° 22′	648, 351 } 297	7.59	+22.54	981.77	Road crossing section line.
Level.......	5.00	986.77				
	10.01	991.36	5.42	....	981.35	Ewing school house.
			5.00	....	986.36	
Stadia......	+1° 30′	788, 221 } 567	2.62	+14.86	1001.22	Skelly limestone, buff. No fossils.
Level.......	7.27	1008.49				
			5.00	....	1003.49	
Stadia......	−4° 46′	692, 311 } 381	8.28	−31.55	971.94	B.M. Road Crossing. □ cut in culvert. 972.

FIG. 24.—Notes for Stadia Survey, Intermingled with Level "Shots." In this case the middle cross-hair is set on the rod at five feet, same being the elevation of the instrument above the ground.

circle. To determine the horizontal and vertical distances, trigonometric formulæ are used, as we have a right-angled triangle with an acute angle and the hypothenuse given. The calculations may be made by means of tables, diagrams, specially constructed stadia slide-rules, or Beaman Stadia Arc. As diagrams and slide rules cannot well be taken into the field, the use of the Beaman Stadia Arc or tables are recommended. (Fig. 24.) (Table XIV.)

If the readings are, for vertical circle 15° 20′ and the intercept on the rod is 2.58 feet, the stadia interval of the instrument being 100 and the instrument constant 1.00 the method of calculation is as follows:

	Hor. Dis.	Ver. Dis.
From the table under 15° 20′ we get	93.01	25.50
Instrument constant 1.00	.96	.27

the horizontal distance equals:

$$93.01 \times 2.58 + .96 = 240.93$$

the vertical distance equals:

$$25.50 \times 2.58 + .27 = 66.06$$

This method of figuring is all that is necessary if the middle hair is placed upon the rod at a height equal to the height of the instrument above the ground. If this is not the case a corresponding correction must be made, which will be the difference between the height of instrument above the ground and the reading of the middle cross-hair, and this difference is to be *added* if the reading on the rod is *less* than the height of the instrument, and *subtracted* if it is *greater*.

Adjustment of the Transit. Set up the transit, level up plate bubbles and turn the instrument 180°. If the bubbles stay in the center they are in adjustment, if not, correct by bringing bubbles towards the center one-half the distance, with adjusting pins, the other half by leveling screws.

Line of collimation. For this adjustment select a point on the ground to which the telescope is to be directed, clamp motion

and *plunge* the telescope and place a mark on a well-defined object where the vertical cross-hair cuts a horizontally drawn line. With telescope still inverted, loosen motion and turn back and sight first point with telescope still inverted, then with motions clamped, plunge telescope again and make another mark on the same horizontal line as in the first case. If adjustment is O. K. the cross-hair will bisect the first point, if not, adjustment is to be made for one-quarter of the error by loosening the screws on the side of the telescope.

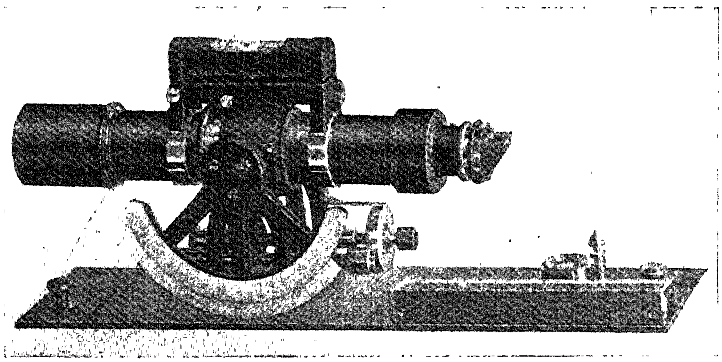
Horizontal axis. After instrument is set up, sight the instrument on a plumb line or at a point up on the side of a building, depress telescope and set a point where the vertical line cuts a horizontally marked line along the side of the building. Reversing the instrument in azimuth and altitude, sight again at first high point and depress instrument again, making another point along the horizontally drawn line on the side of the building. If both marks coincide the axis is in adjustment, if not, correct for one-quarter of the error by means of the horizontal reticule adjusting screws, moving the reticule in a direction that would apparently increase the error.

Attached level. This adjustment is the same as the one required in the adjustment of the level for the wye adjustment, but as the telescope and level in a transit cannot be turned end for end in the wyes, it is adjusted by the two-peg method. (This method is also used in similar adjustment for the Dumpy level.) The procedure is as follows: set up the instrument, level telescope, set a peg 300 feet from the instrument and take the rod reading, set another point 300 feet from the instrument in the opposite direction and take the rod reading. The difference of elevation of these two points may be determined from these figures even with the instrument out of adjustment, as the back and foresights are equal in length. Move instrument and set up one or two feet from one of these pegs, hold rod on peg, turn the telescope and looking into the *object end*, the reading on the rod in the small field of view may be noted by bringing the point of a pencil to the center. The target is set at this point, plus or minus the difference in the elevation of the two pegs, then set

rod on the distant peg and if instrument is in adjustment, the horizontal cross-hair will cut the target exactly; if not, adjust for the whole error by means of the reticule adjusting screws.

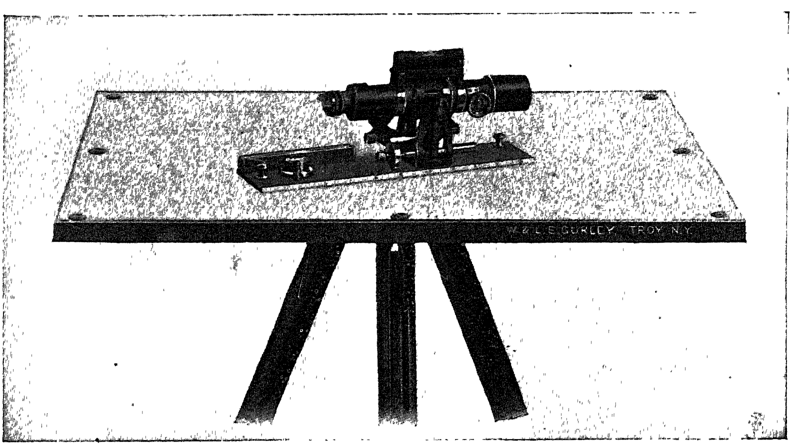
THE PLANE TABLE

A plane table consists of an alidade carrying a line of sight attached by a support to a ruler with a fiducial edge. The



(Courtesy W. & L. E. Gurley.)

FIG. 25*a*.—Gurley Explorer's Alidade with Beaman Stadia Arc.

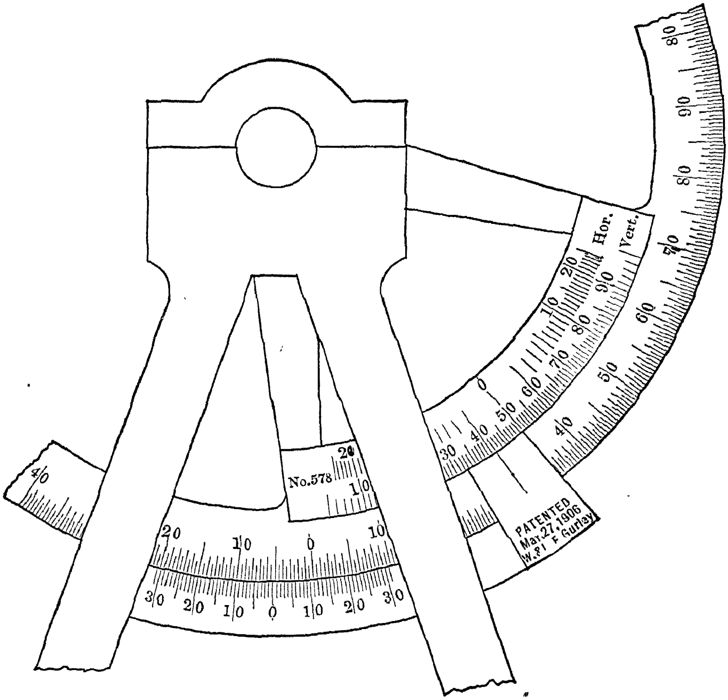


(Courtesy W. & L. E. Gurley)

FIG. 25*b*.—Explorer's Plane Table Outfit.

alidade is free to move on a drawing board mounted on a tripod and the table is leveled by means of plate levels. The alidade consists of a telescope provided with a level tube, a vertical circle and stadia wires. (Fig. 25.)

To facilitate computations of horizontal and vertical distances an attachment known as the Beaman Stadia Arc has been



(*After W. & L. E. Gurley.*)

FIG. 25*c*.—Enlarged View of Graduations of Beaman Stadia Arc.

patented, and which may be attached to the vertical circle of transits as well as plane table instruments and by means of which stadia tables or slide rules may be eliminated, the vertical angles are not read and yet the results are obtained much quicker and with accuracy equal to that obtained by the other methods; and its simplicity tends to eliminate errors that might otherwise occur. The Beaman Stadia Arc patent is controlled and manufactured by W. & L. E. Gurley, (Troy, N. Y.) and their

description of the method of computations is as follows: (Fig. 25*c*.)

Difference in Elevation between Instrument and Rod. The outer scale, marked "Vert.," indicates multiples of the rod interval, for determining differences in elevation between instrument and rod. The zero point of this scale is marked 50, so that a direct scale reading will indicate whether the telescope is elevated or depressed.

A unique feature of the use of the multiple scale is that only such inclinations of the telescope are used as will give a whole number scale reading, while the fractional part of the elevation is quickly and accurately determined by the reading of the middle wire on the rod.

To obtain the desired multiple, therefore, sight anywhere on the rod, it does not matter where, so that a whole number reading is obtained on the multiple scale.

Subtract 50 from this scale reading and use the algebraic remainder; e.g., if the Vert. scale reads 56, the multiple is $56-50=+6$. If the scale reads 47, the multiple is $47-50=-3$.

Example: Suppose the observed subtended stadia reading on the rod to be 6.40 (640 ft.), and to obtain a whole number for the scale reading, the telescope is inclined so that the multiple scale reads 33, at which setting the middle wire reads 7.30 on the rod.

Then the desired multiple equals $33-50=-17$
and $-17\times 6.40=-108.8$

Difference in elevation between instrument and base of rod is then,

$$-7.30-108.8=-116.1 \text{ ft.}$$

The negative point indicates that the point where the rod was held is lower than the instrument.

To Reduce Observed Distance to True Horizontal Distance. The inner scale, marked "Hor.," gives at the same pointing a direct reading of the percentage of correction (always subtractive) necessary to reduce the observed stadia reading (in feet subtended) to the true horizontal distance.

Example: At the above setting the reduction scale would read 3, or 3%.

$$3\% \text{ of } 640 \text{ ft.} = 19.2 \text{ ft.}$$

$$640 - 19.2 = 620.8 \text{ ft., the true horizontal distance.}$$

To facilitate the slight computation necessary to determine differences in elevation, a special form of notes as devised by the United States Geological Survey for use with this attachment is as follows:

Stadia Arc Reading.		Distance.	Product.	Rod Correction.	Difference of Elevation.	Elevation.	Station.
B.S.	F.S.					654.7	B.M.
54		4.2	− 16.8	+ 8.2	− 8.6	646.1	H.I.
	48	6.3	− 12.6	− 4.9	−17.5	628.6	T.P.
44		9.2	+ 55.2	+ 4.3	+59.5	688.1	H.I.
	57	15.8	+110.6	−13.8	+96.8	784.9	T.P.
50		8.4	....	+ 6.7	+ 6.7	791.6	H.I.
	50	5.6	....	− 9.8	− 9.8	781.8	T.P.

The Beaman Arc reading is placed under the appropriate heading, B.S. or F.S., in the above table. All sights are to be regarded as foresights, except those taken to determine the H.I. Thus, after B.S. has been taken to determine the H.I., all intermediate rod stations, whether taken before the rod reaches the instrument or after the rod goes ahead, are to be entered as foresights.

The distance is recorded as 4.2, 6.3, etc., meaning 420 feet, 630 feet, etc.

The column headed "Product" is for the multiple times the distance, for example $4 \times 4.2 = 16.8$; 4 being the multiple for a stadia arc setting of 54.

The column headed "Rod Correction" is for the final reading of the middle wire on the rod.

The signs to be affixed to the "Product" and to the "Rod Correction" are determined according to whether the observation is a B.S. or a F.S., by following a rule of universal application, namely:

	Product.	Rod Correction.
B.S.	Opposite sign to that indicated by arc reading......	+
F.S.	Same sign at that indicated by arc reading.........	−

A stadia arc reading of 54 indicates +; therefore, here the sign of the "Product" is − for a B.S., and + for a F.S.

Note that the sign of the "Rod Correction" is the same as in leveling.

When the line of sight is level, the stadia arc reading is 50, and hence the multiple is 0, which gives a "Product" 0. The only entry is, therefore, the "Rod Correction," or the final rod reading, whose sign follows the above rule.

Take the "Product" and the "Rod Correction" by pairs, and add algebraically; e.g., $-16.8+8.2= -8.6$, the "Difference of Elevation." This, applied algebraically to the last known elevation, gives the elevation desired.

Upon the drawing board, or plane table, a sheet of drawing paper is firmly attached, on which the observations in the field are to be recorded at the time they are made. The table is set up in its proper position (oriented) over a known or unknown point. By keeping the ruler on the point representing the occupied station, the telescope is turned upon other objects and lines are drawn towards them. This will give the direction of the desired point from the table, and its horizontal distance or the difference in elevation determined by stadia. Horizontal distances are sometimes measured with chain; and quite often points are located by means of triangulation from two known points. As it is almost impossible to keep the table perfectly level, the bubble of the instrument is to be kept level and the error of the vernier reading determined and which is to be accounted for in each vertical reading.

The plane table is the instrument used to a great extent in geological surveys. By means of it topographic and geologic mapping of a territory may be made simultaneously. The principal methods used are: radiation, traversing, intersection and resection.

Radiation. In this method a convenient point on the paper is set over a selected point, the table oriented and clamped, each point which is to be located is sighted and a line is drawn along the fiducial edge towards them in turn. The distance and elevation measured by stadia (or by chaining for distance). (Fig. 26.)

Traversing. This method is similar to traversing as done with a transit, and consists in moving the plane table from one point

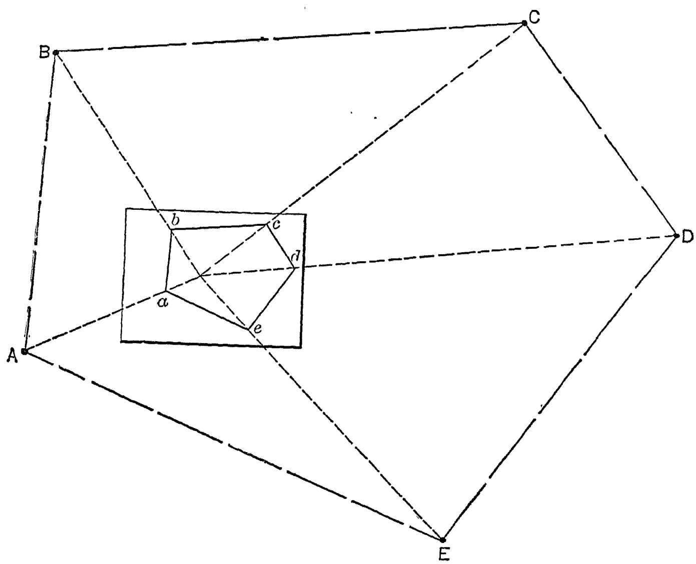


FIG. 26.—Method of Radiation with Plane Table.

to another, then back sighting to the station just left, so the table is always carefully oriented. This is one of the simplest methods in use and is most generally combined with the method of radiation. (Fig. 27.)

Intersection. When points are located by a system of triangulation from a carefully measured base line, or any known line, the points are located by intersection. The method employed necessitates the orienting of the plane table at one end of a known line, then the point required is sighted and the direction drawn by means of the fiducial edge; the table is then

moved to the other end of the line, the table oriented, and the point previously sighted from the first point is again sighted from

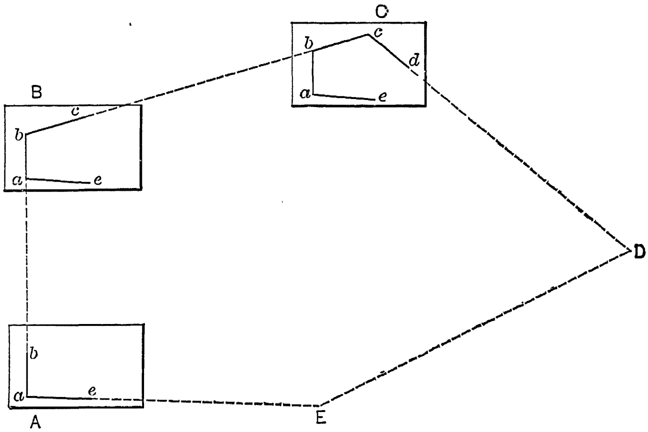


FIG. 27.—Method of Traversing with Plane Table.

First occupying station *A*, locating points *a*, *e*, and *b*. Next, moving to station *B*, orienting by back-sighting at *A*, with fiducial edge along line *ba*, thirdly, moving to *C*, orienting by back-sighting to *B*.

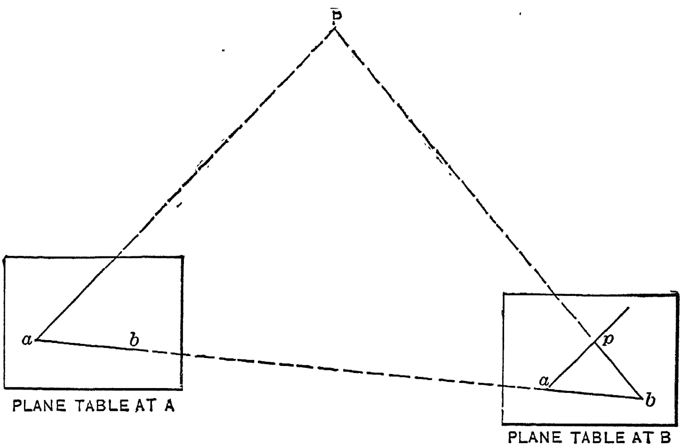


FIG. 28.—Method of Intersection.

For locating point *P* with the plane table set up at each end of a measured base line *AB*.

this second point, the line drawn again, and the intersection of the two lines will determine the location of the point sighted.

This system is best employed in finding of distant and not easily accessible points, and may be used in keeping a check on the progress of the work, with previously determined stations. (Fig. 28.)

Resection. The previous method necessitates the setting of the instrument over a known point, but in the course of work it may sometimes be more convenient to set over a point that has not been previously located. This may be done by resection. which consists of setting up the plane table at a random point and orienting it with respect to either three or two known points, which may be done by means of special problems, and in orienting with respect to three points it is accomplished by the three-point problem, and in case of two points, by the two-point problem.

Three-point Problem. There are several variations of this solution, known as the mechanical solution, the Coast Survey solution, Bessel's solution and the analytical solution. The problem is indeterminate if a circle can be passed through the three points and the selected fourth point.

The mechanical solution requires the setting of the instrument at an unknown point P (Fig. 29) not plotted on the board, from which three points, A, B, and C, platted at a, b, and c, respectively, are visible but whose distances from our selected point cannot be measured conveniently. A piece of tracing cloth is fastened over the plane table; and the table oriented approximately with the eye, and a point p' is selected on the tracing cloth which approximately corresponds to the true position of p. Lines $p'c'$, $p'b'$ and $p'a'$ are platted as if p' were the correct point p. We have two angles subtended by three points plotted graphically on a tracing cloth, and the point sought is located by placing the tracing cloth over the plotted points as follows: unfasten the cloth and move it to the position $p''a''$, $p''b''$, and $p''c''$, in which each line $p'a'$, $p'b'$, and $p'c'$ pass respectively through the points a, b, and c. The point p'' is then over the exact position of p, which is to be marked on the board. The plane table can then be oriented accurately by means of any one of the lines pa, pb, or pc.

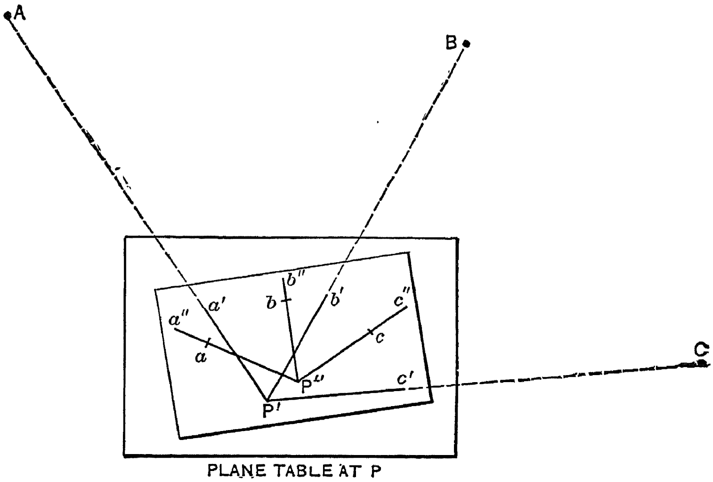


FIG. 29.—Three-point Problem, Mechanical Solution.

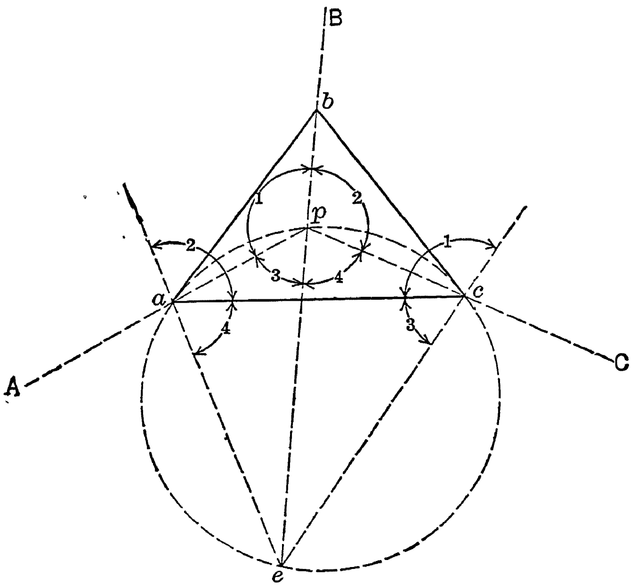


FIG. 30.—Three-point Problem, Bessel's Solution.

The Bessel's solution (Fig. 30) necessitates the use of the three plotted or known points *a*, *b*, and *c*, and the random point P. Construct an angle 1 with vertex at point *c* as follows: sight along the line *ca* at the point A on the ground, clamp the vertical axis. Center the alidade on *c* and sight at B and draw a line along the fiducial edge. Construct the angle 2 with vertex at point *a* in the same manner. The line joining *b* and *e* will pass through the point *p* required. Orient the board by sighting at B with the line of sight along the line *eb* and locate *p* by resection.

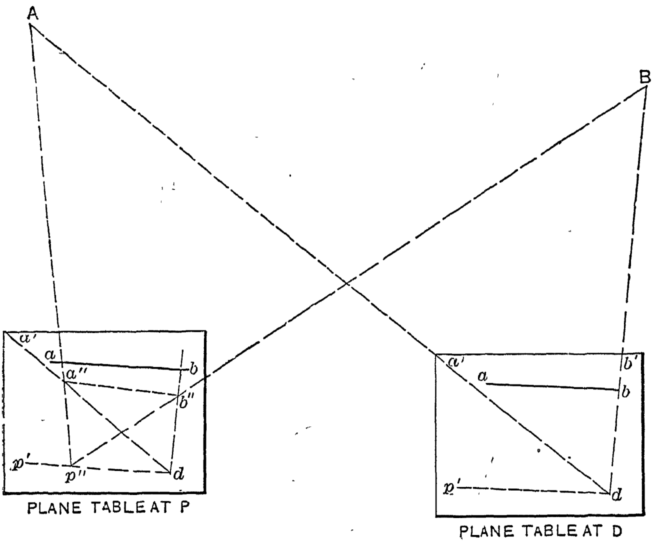


FIG. 31.—Two-point Problem.

Two-point Problem. When two points A and B (Fig. 31) on the ground are platted on the plane table at *a* and *b*, are visible, the platted position of a third or required point P may be determined by establishing through it a line parallel to AB and orienting the table by means of that line. Set up the plane table at D, orient it approximately by the eye and plat the point *d* and the lines *dp'*, *da'*, and *db'*. Pick up the table and set up at P and orient it with reference to the line PD by placing the fiducial edge on the line *p'd* and sight station D. Through any point *p''* on the line *p'd* plat the lines of sight to B and A,

the intersection of which with da' and db' will be points a'' and b'' respectively. The line $a''b''$ is then parallel to AB. Placing the fiducial edge on the line $a''b''$ and make a mark along this line about 500 feet from P, in this way establishing a line parallel to AB. The board is now unclamped and with the fiducial edge on line ab and turned until the line of sight bisects the mark, making ab parallel to AB. The table is then clamped and the fiducial edge in contact with a and b in turn, the telescope is directed to points A and B and the lines pa and pb are drawn. The intersection of these lines will give the platted position of the point p.

Adjustments. The necessary adjustments for the plane table are (1) the plate level, (2) line of collimation, (3) the horizontal axis, (4) the attached level. The adjustments are made similarly to those of a transit.

Summary. Preliminary surveys are made by the use of approximate methods and the resulting work will not be accurate for all purposes, but for certain work it has the advantage of being rapidly made and with small expense. The preliminary survey is usually followed by the precise methods which involve the use of the various instruments, and for all important geological work they should be used, and all elevations should be referred to sea level and level work checked in all cases at the starting B.M. or at any other point, where elevations may be known.

CHAPTER VIII

MAPS

DEVELOPMENT work of an oil company is based on information carried by maps which are constructed for that purpose. The various maps so employed are the Topographic, Farm and Geological maps.

TOPOGRAPHIC MAPS

A topographic map is one which shows the general lay of the land surface. On it will appear all creeks and rivers, hills, valleys and mountains; houses and towns, roads and railroads; so that anyone capable of understanding and interpreting the maps will see a clear picture of the land so mapped.

The United States Geological Survey has undertaken the great task of making topographic maps of the entire country and at the present time about one-third of it has been so mapped. These maps are in general use and are considered as a standard in topographic mapping. (Fig. 32.)

The country has been divided into rectangles known as Quadrangles, the boundaries of which are certain parallels and meridians, or as generally referred to as latitudes and longitudes. The location of the territory which the map shows is indicated by a name which has been given to it from some important town or feature that the territory may possess, or it may be known by the controlling meridians. The maps are made to three different scales, the largest one being a scale of $\frac{1}{62,500}$, by which is meant that a distance of one inch on the map will equal 62,500 inches on the ground, or one inch on the map will nearly equal one mile on the ground. This scale is employed in sections of large population or important industrial centers. For the greater part of the country a scale of $\frac{1}{125,000}$ or one inch to nearly two

miles, is used. In the desert regions of the Far West a scale of $\frac{1}{250,000}$ or four miles to an inch scale is used. For some important mining regions, special or larger scales have been employed to some extent.

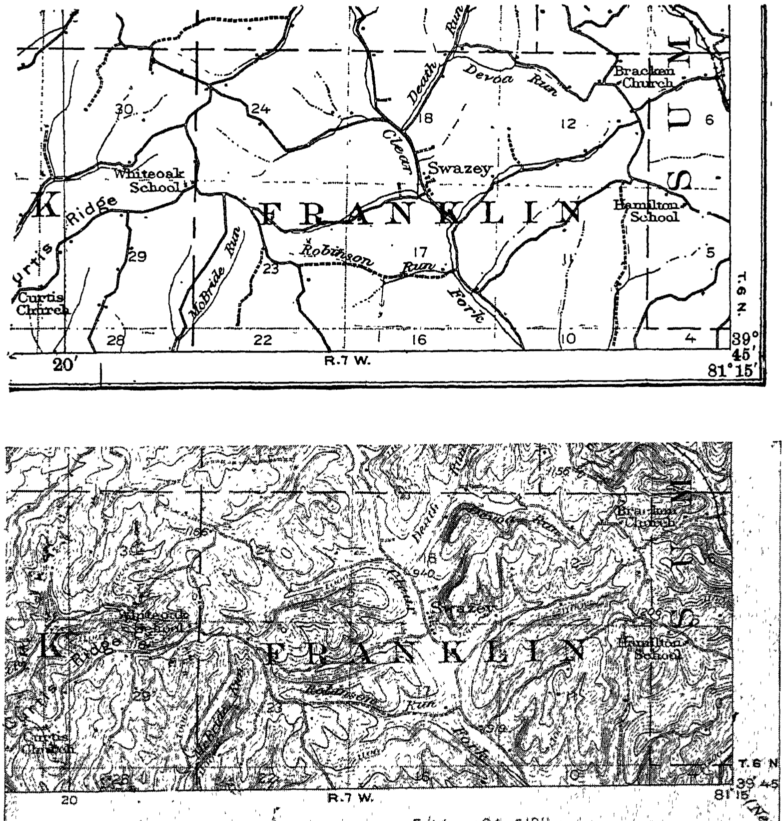
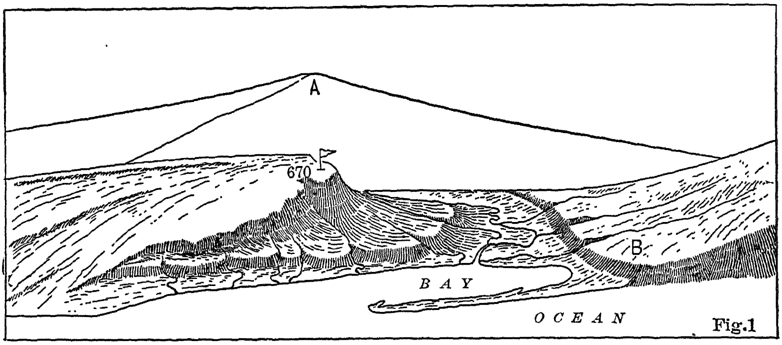


FIG. 32.—Topographic Maps.

Top figure without contours; bottom figure same area with contours. (From U. S. G. S. Topographic map.)

The general scheme of representing the various surface features is based on the use of three colors, so that the works of man, known as *culture*, such as houses, railroads, roads, bridges and towns are drawn in black. Creeks, rivers, lakes,

seas or water of any kind are shown by blue coloring, while the relief or the surface elevations and depressions, such as hills, mountains and valleys are depicted by brown figures and brown



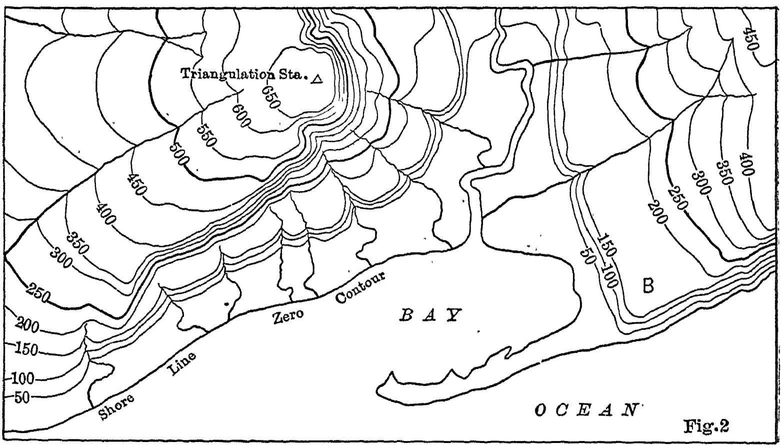


FIG. 34.—Landscape with its Corresponding Topographic Contour Map below it.

The mountain marked *A* in the upper map does not show on the contour map. (U. S. G. S.)

contour lines. (In some of the latest maps, a fourth color, green, has been used to represent wooded areas.)

Various conventions are used to represent certain features, and they may best be understood by a study of the accompany-

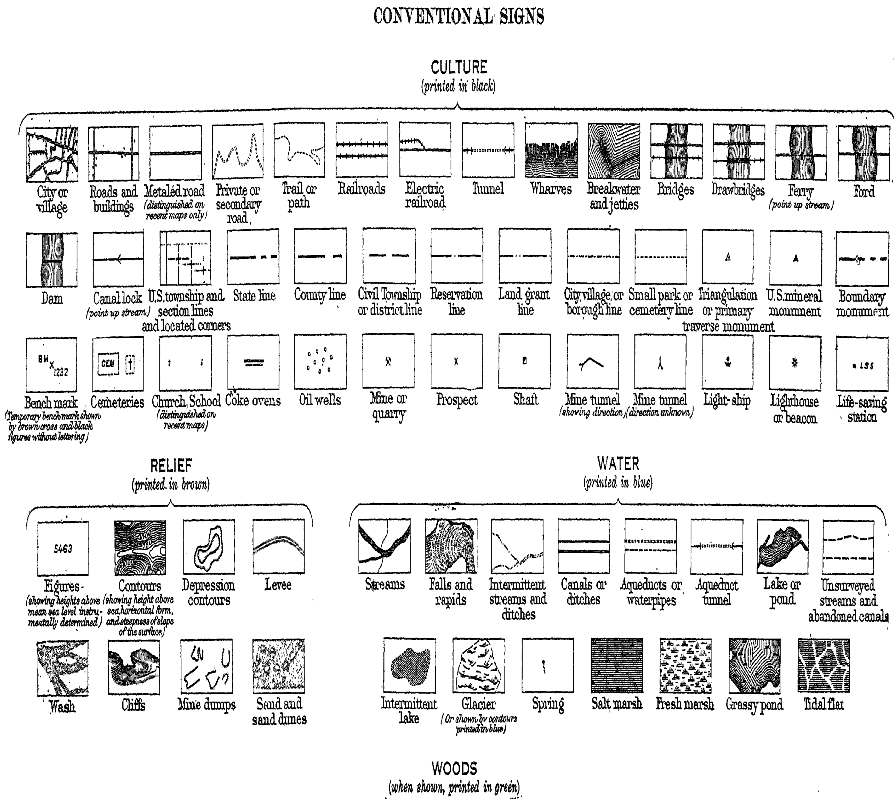


Fig. 33.—Topographic Conventions. (After U. S. G. S.)

To face p. 70

ing table of conventions, on which a number of the common symbols are shown. (Fig. 33.)

Contour Lines. When points having the same elevations are connected by a line, the resulting line is known as a contour line. (Fig. 34.) If one follows a contour on the ground, he will be going neither up hill nor down hill but will maintain the same altitude all the time. So each line represents a certain elevation, which in the case of government topographic maps are based on mean-tide as a datum plane. A scale of 20 feet contour interval indicates, that the difference of elevation from one line to the next one is 20 feet. By the use of these lines it is a simple process to show hills and valleys very plainly, not only their shape and form are shown but the differences in altitude are recorded by them. Certain lines, generally the fifth ones, show by the figures on them the elevation they represent; thus, the 500 foot contour will indicate the points on the earth's surface which are 500 feet above sea-level. The grade or steepness is also indicated by the contours, and upon observation it will be seen that when the lines are close together they indicate steepness and when they are further apart the slope is a gentle one. It must be understood that contour lines can never cross each other, and that they will always close upon themselves; this may take place in a small area or may be noticeable only if a large territory is examined.

Besides the contour lines, figures are also used to denote the elevations, thus prominent points, such as railroad or road crossings or prominent hills may be marked by brown figures indicating the elevation of that point to the nearest foot. Many bench marks (B.M.) or points of exact elevations have been established, and are marked by permanent metal tablets. Such elevations have been very carefully determined and known to the nearest thousandth of a foot.

FARM MAPS

Farm maps, as the name implies, show the size, extent and shape, as well as the ownership of the farms. (Fig. 35.) The best farm maps are made with the topographic map used as a base; that is, the topographic map is enlarged, generally to a scale of four inches to a mile; the contour lines left off (brown

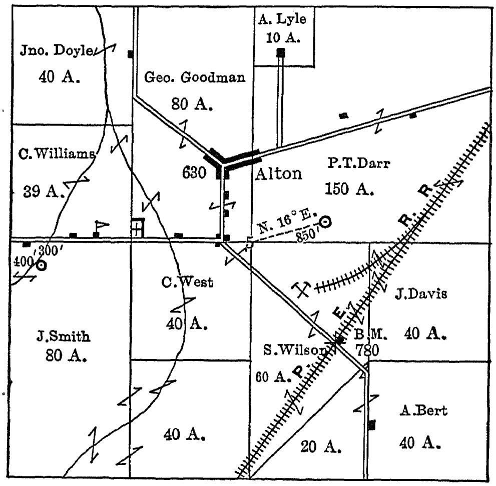


FIG. 35.—Farm Map, Area Represented is One Square Mile, or One Section; also Showing Methods of Well Location Surveys.

Rectangular method: location on J. Smith 80-acre tract in section 5. 300 feet south of the north line, 400 feet east of the west line. Bearing method: location on P. T. Darr 150-acre tract in section 5. From corner stone at southwest corner of property 850 feet bearing north 16° east.

figures may be left on), and the farm lines and other information added. An existing farm line map may easily be combined with the topographic map, or the description of the farms obtained at the proper courthouse and the maps constructed from the deeds. The best farm maps are so constructed. Of course, a survey of the farm is necessary if data are not obtainable otherwise.

In the Eastern States, Pennsylvania, West Virginia, etc., the farms are irregular in shape, but a rectangular system of land

division has been provided by Acts of Congress at various times, requiring the subdivision of land surface into rectangles; so at first six-miles square rectangles were laid out and referred to as townships and ranges, later it was decided that the six-mile square townships be further subdivided into rectangles of one

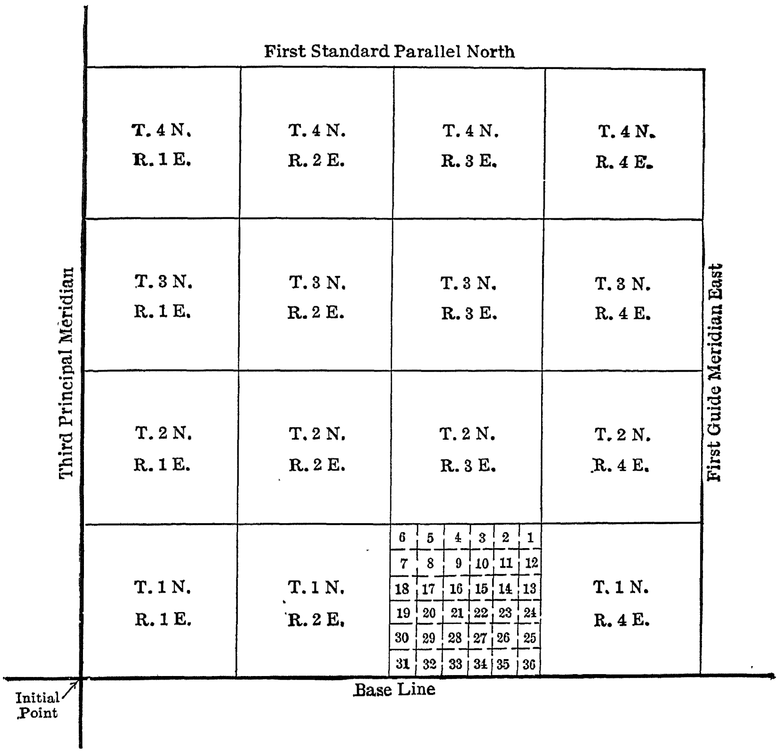


FIG. 36.--Subdivision of Land into Ranges and Townships.

T. 1 N., R. 3 E. is shown subdivided into sections.

square mile and known as sections, giving thirty-six sections to a township and numbered accordingly from one to thirty-six, with section one in the northeast corner and thence west and east alternately up to thirty-six, in the southwest corner. Later half section lines were also authorized to be run, further subdividing the land into smaller but always rectangular por-

tions. Thus in a section of one square mile we have 640 acres, a half section 320 acres, 160 acres to a quarter section. The letter of the law could not be followed out, as it is impossible to set out

WELL CONVENTIONS

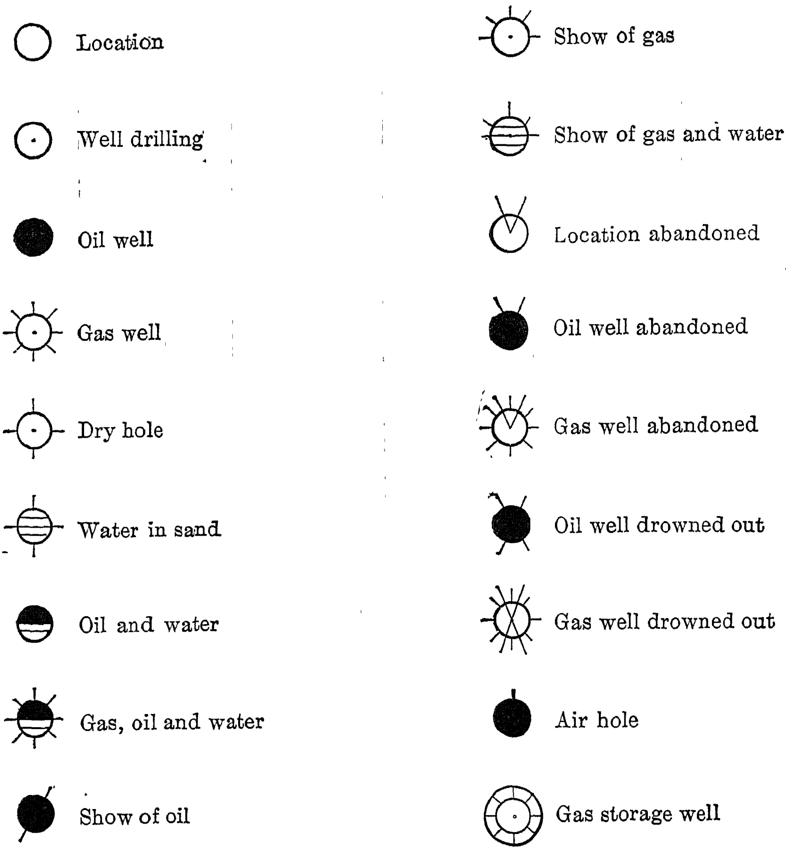


FIG. 37.

true rectangles on a spherical surface, and a certain error is obtained which is generally proportioned into the northern tier of sections. (Fig. 36.)

A farm map is used to show the leases held by a company as

well as the leases of a competing company; various colors are in use to indicate the various leaseholds. The maps also show the proper location of all wells.

The systems employed in surveying well locations are two in number, the rectangular method and the bearing method.

The rectangular method necessitates the use of a measuring tape or chain, or may be paced; and the locations are measured at right angles to the farm lines. Many States require this method for well locations and it is the most advantageous, as it is easily made and the distances from the property lines are known. Such locations may easily be described verbally; thus the statement that a well on the J. Smith farm is 300 feet south of the north line and 400 feet east of the west line is easily understood and the corresponding location on one's own map made. (Fig. 35.)

The bearing method necessitates the use of a transit or compass, and the location is indicated by the distance a well is from the nearest corner stone of the farm and the magnetic bearing of that line. This method is inferior to the rectangular method, and should be avoided wherever possible. (Fig. 35.)

GEOLOGICAL MAPS

Maps dealing with the various phases of geology, such as areal geological maps, structure maps, isobath, isochore, isopachous and other similar maps are considered under this heading.

Areal Geological Maps. These maps show the location of the geological formations that outcrop at the surface; the value of which is to acquaint one with the various rocks that will be encountered in the field, also it may give certain hints as to the presence of folds and faults. (Fig. 38.)

Structural Maps. Structural geology deals with the deformation and attitude of the strata and the relation of the rocks to one another. There are various ways to depict structural features, but the best and simplest method is by means of contour lines used to denote the elevations and depressions of the strata.

Such maps are known as isobath maps or sometimes structure contour maps, and they show graphically the various folds and faults over the territory that has been examined.

The use of contour lines becomes very valuable in this con-

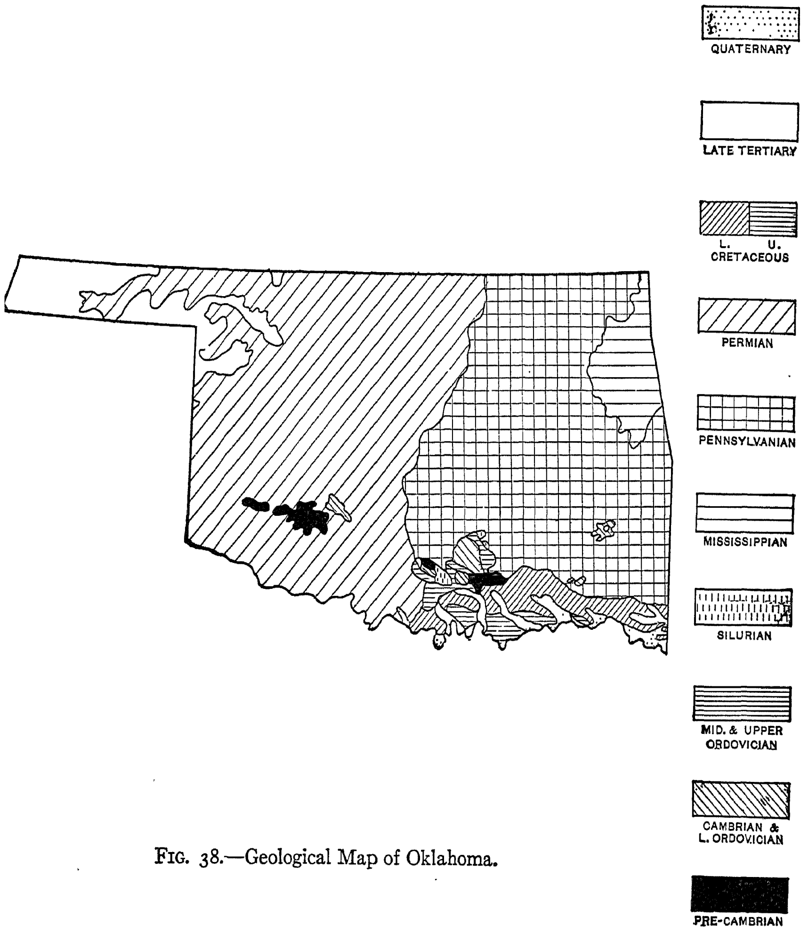
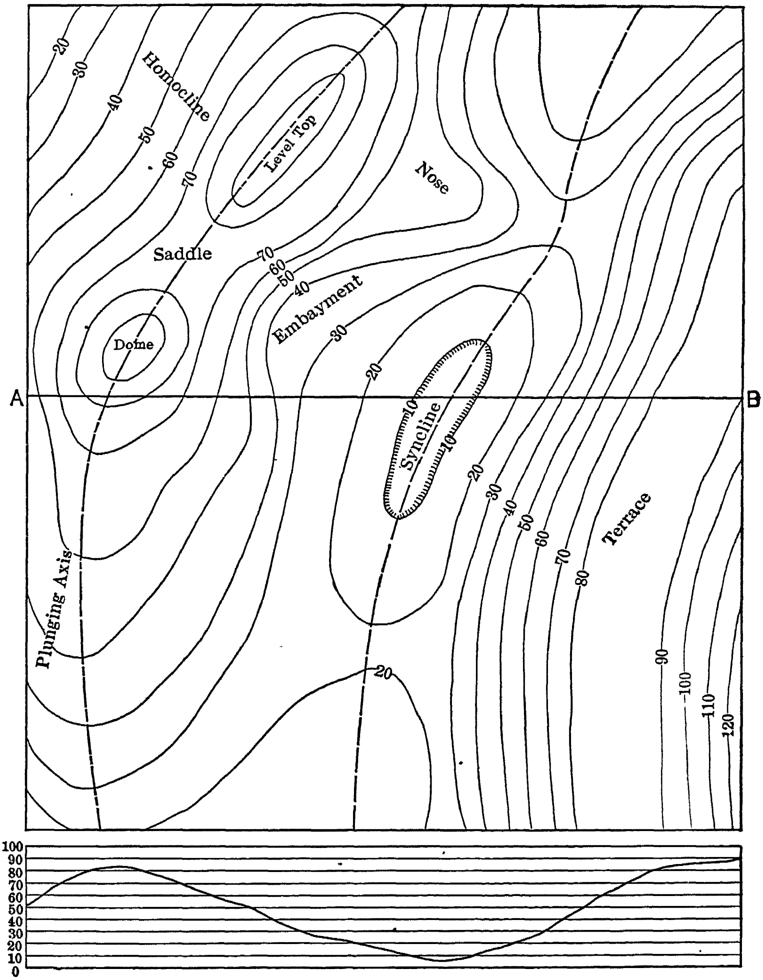


FIG. 38.—Geological Map of Oklahoma.

nection as by means of it the various facts may be shown. Thus we may indicate the dips of a stratum, the thickness of the stratum as well as convergence or lateral variation between strata. For this reason a thorough understanding of contour lines must be

had, as well as the distinction between the surface contours and structural contours.



Profile along line *AB*.

FIG. 39.—Isobath or Structure Contour Map, Showing the Various "Structures" Encountered in the Oil and Gas Fields. Contour interval 10 feet.

Isobath Map. The object of this map is to show the dips of a stratum. (Fig. 39.) Such a map is constructed from the data

FIG. 40*a*.

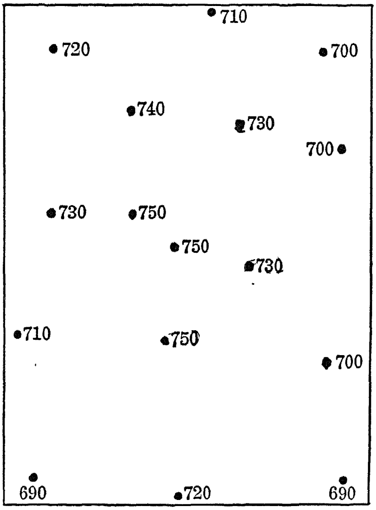
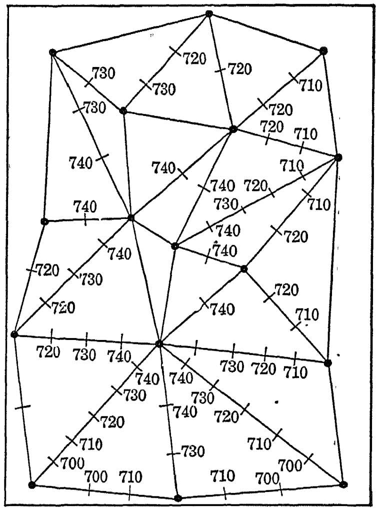


FIG. 40*b*.



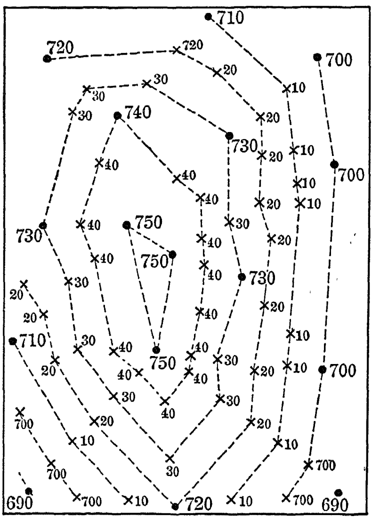


FIG. 40*c*.

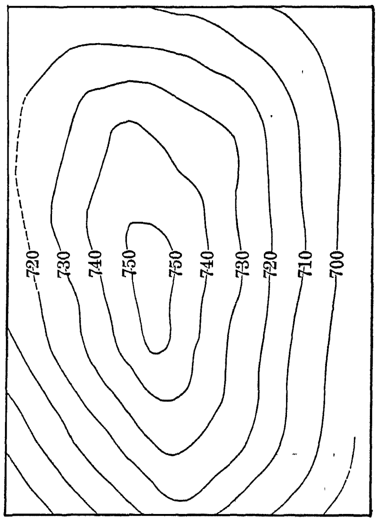


FIG. 40*d*.

FIG. 40*a*.—Location and Elevation of Key-horizon as Determined in the Field.
FIG. 40*b*.—Mechanical Interpolation of Unknown Elevations between the Known Ones.
FIG. 40*c*.—All Points of Equal Elevations are Joined Together (Contoured).
FIG. 40*d*.—The Finished Isobath or Structure Contour Map of a Surface Key-horizon.

obtained in the field during the course of the geological work. The elevations of a key-horizon are determined, and if more than one key-horizon has been used, they are to be reduced to a common one by the addition or subtraction of the interval between them. The elevations thus determined are plotted on a map in their proper places, and contour lines or isobaths are drawn through the points having the same elevations. It is quite often necessary that certain mechanical computations are to be made to obtain all the points through which the lines are to be drawn; thus if we have two figures of 520 and 550 feet and we intend to use 10 feet contour interval, it will be necessary to determine the points where the 530 and 540 feet lines are to pass through, so their position is to be interpolated between the known points of 520 and 550. (Fig. 41.) From this it will be seen that the accuracy of the map depends on the number of elevations of outcrops and their proximity to each other. An isobath map that is constructed in this way will show the various dips of the strata in a graphical way, it will be correct for the various deformations of the key-horizon, and it will give us an idea what such a key-horizon would look like if the entire surface soil had been stripped off. The completed map will show all anticlines, synclines and other structures existing in the territory so mapped. (Fig. 40.)

Isochore Map. The isochore map or convergence sheet is used to assist in making an isobath map of the *producing horizon* from an isobath map of a *surface* or *key-horizon*. In most places, the interval or the distance between a key-horizon and the oil- or gas-bearing stratum may not be the same, and will vary from place to place, thus at one point, for example, the interval will be 1500 feet, and about four miles further east the interval between the same two strata may be 1540 feet, in other words the lateral variation between the two points will be 40 feet. The information can be obtained from well records only, and the more numerous the records the more correct will be the convergence sheet, which is constructed as follows: The position of each well whose record is used is plotted in its proper place and the interval between a key-horizon and the producing horizon is

noted alongside the well, with these figures as a basis a contour map is constructed, which when completed will show the points along which the interval is the same, in other words each line or isochore will represent equal intervals. (Fig. 41.) Such a map should be made on tracing cloth or other transparent material. The next procedure is to combine the isobath map of

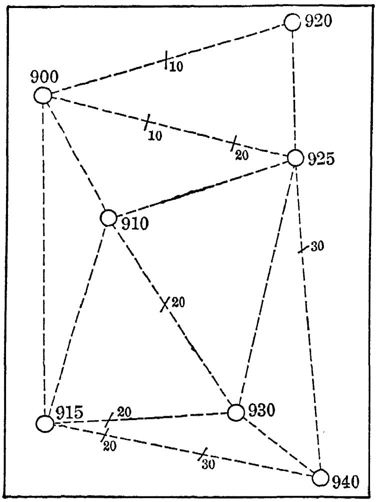


FIG. 41*a*.

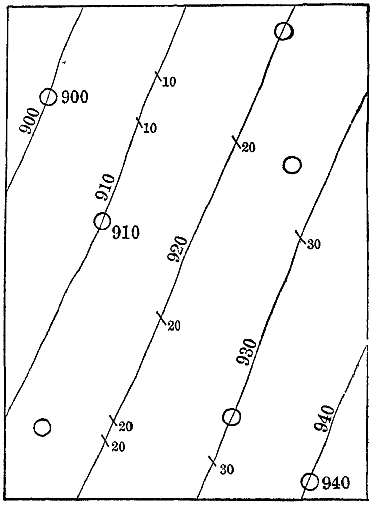


FIG. 41*b*.

FIG. 41.—Isochore (equal thickness) Map.

FIG. 41*a*.—Location of wells, the records of which are used for the construction of this map. The figures alongside of the wells show the interval or distance between the surface key-horizon and the producing sand. The interpolated unknown points are also shown.

FIG. 41*b*.—The completed isochore map; each line or isochore shows the points along which the interval is constant between the surface key-horizon and the producing sand. This map is sometimes known as a Convergence sheet.

the surface key-horizon and the isochore map, which is as follows: the isochore map is superimposed over the isobath map, and the figure of each isochore is subtracted from the figures of the isobath at every point where they cross each other, obtaining a new set of figures, which, when contoured, will be the isobath map of the producing horizon, as the figures resulting from such operation will be the elevation of the producing sand at that

point with reference to the chosen datum plane. (Fig. 43.) Lateral variation in most instances is quite regular in a certain direction, that is, it may be that the intervening strata causing such a variation thicken in a certain direction at a certain rate, or as may best be expressed by the statement that a certain stratum has a lateral variation of 10 feet per mile southeast.

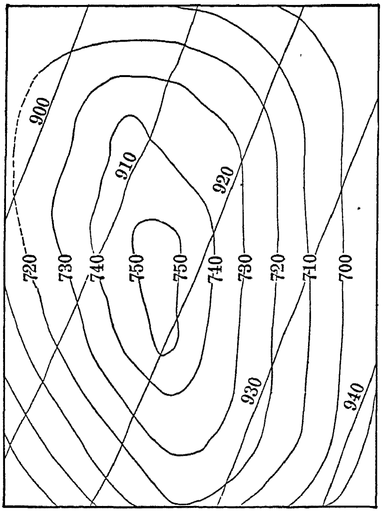


Fig. 42a.

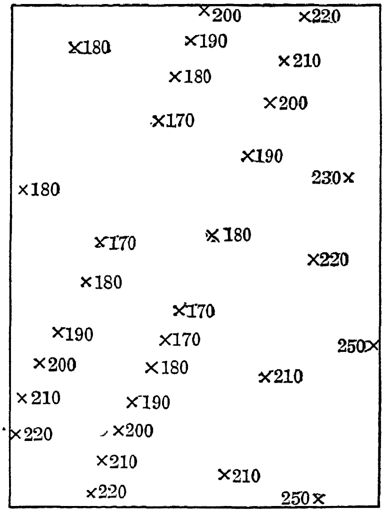


Fig. 42b.

Fig. 42a.—The isochore map (Fig. 41b) is superimposed upon the isobath map (Fig. 40c).

Fig. 42b.—The figures are obtained by subtracting the isochores from the isobath at every point where they cross each other. The figures of the isochores in this case being greater, the resulting figures are minus, indicating distance below sea-level. These points will show the elevation of the sand as constructed from the two maps.

Lateral variation may be so strong that it may entirely obliterate any surface structure, and where small structures are known a strong lateral variation may obliterate it in such a way that the producing horizon may not show such a structure. This is the case in the "Clinton" sand pools of Ohio, where all the formations thicken towards the east, due to the fact that deposition has taken place along the east flank of an anticlinal fold, where

the folding and deposition took place at about the same time, thus the deposits further from the axis will be in all cases thicker. Many lenticular as well as many new formations and sands may make their appearance under such conditions, away from the axis.

Of course, the value of a convergence sheet is increased with the number of well records that are obtainable. Wherever well

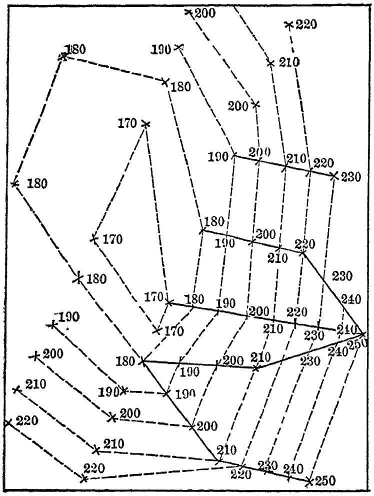


FIG. 43*a*.

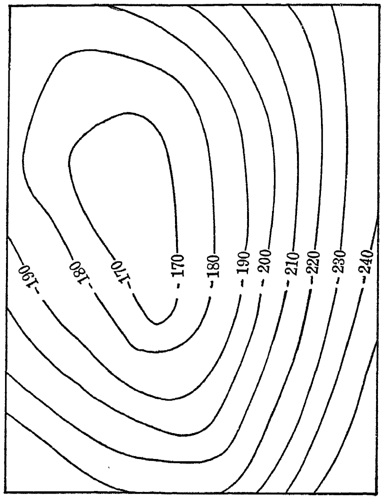


FIG. 43*b*.

FIG. 43*a*.—The Calculated Elevations of the Pay-sand (Fig. 42*b*) are plotted and the unknown points interpolated. The points of equal elevations are joined together.

FIG. 43*b*.—The Completed Isobath Map of the Sub-surface Structure. Compare this map with Fig. 40*d*.

logs are numerous, it is possible to construct an isobath map directly from such records, simply by taking the elevation of the surface at each well, the elevation of the sand computed and the isobath map constructed from those figures.

Another valuable use to which contour lines may be put to is to show the general variation of thickening of a certain stratum, generally that of a "pay-sand." Thus if the figures showing the thickness of a stratum are properly plotted and a contour map

made from those figures the resulting contour map will show the direction and the amount of variation in the sand. Such maps are

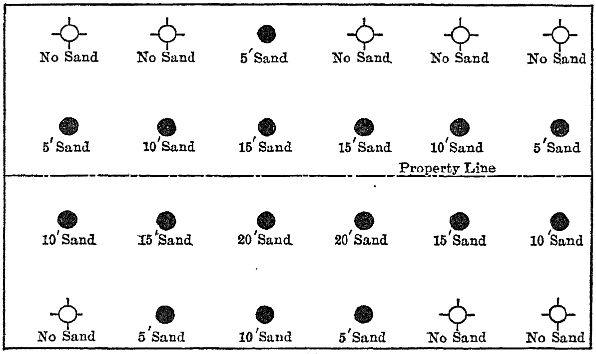


Fig. 44-a

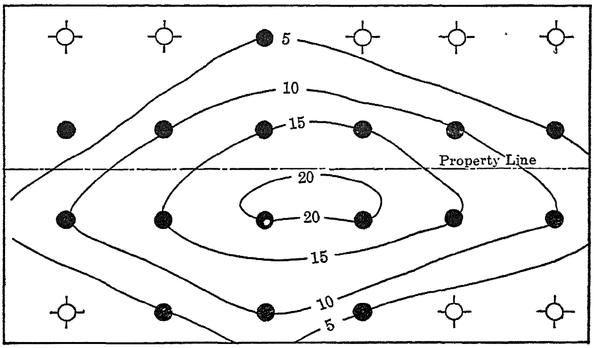


Fig. 44-b

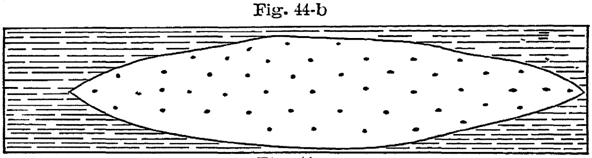


Fig. 44-c

FIG. 44*a*.—Indicates Two Properties Drilled Up. At each hole the amount of sand found is indicated by the figures.

FIG. 44*b*.—The Same Condition is Indicated by Means of Contour Lines, each one showing the points along the sand having equal thickness, in this case the lines are known as Iso-pachous lines.

FIG. 44*c*.—Section of Sand along Property Line.

known as iso-pachous maps, and are of great importance in observing the pinching and swelling of a sand, and as the varia-

tions take place with some regularity, it becomes possible to determine the points where the sand may be expected to "pinch" out entirely. Lenticular sands, as well as porous portions of sandstones, may be mapped in this manner, the data being obtained from well records. (Fig. 44.)

CHAPTER IX

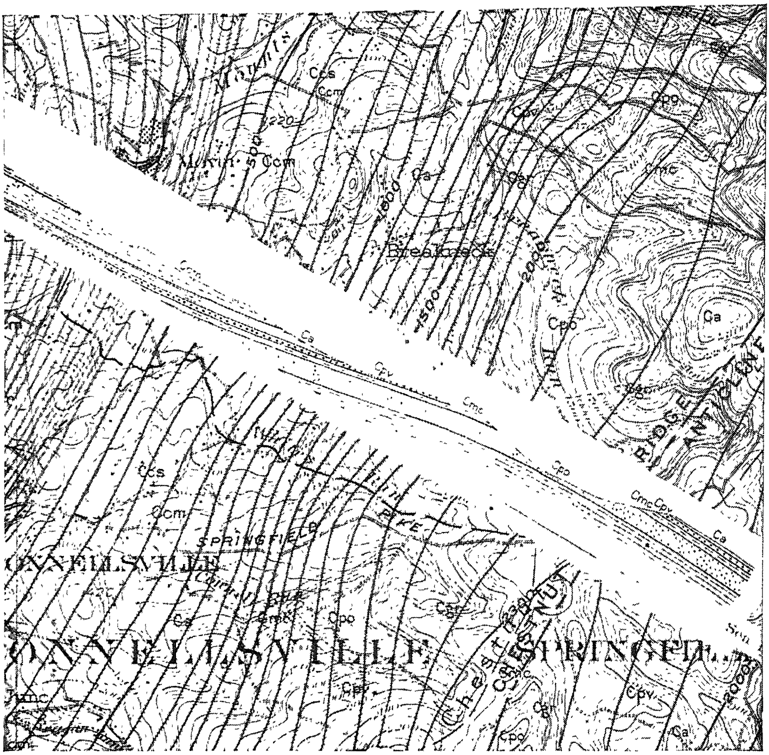
GEOLOGICAL FIELD WORK

THE object of the field examination of a prospect is to collect data from which structural and other maps may be constructed. The methods employed are, the reconnaissance survey or preliminary examination, during which the probable key-horizons may be found, the various wells that have been drilled are looked up, and whatever information regarding them is obtainable. Any geological information that may be had on the territory in question is also to be examined to enable the laying out of a proper scheme for the final or precise survey, by which the field work is completed.

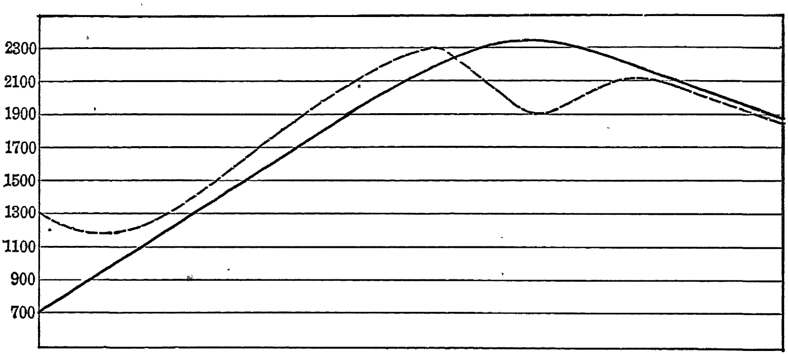
The first step for the prospector before beginning his work in the field is to obtain all the possible information he can from maps and previously published reports. Many clues may be found that may save time or enable the discovery of structure.

In many regions the topography may bear some relation to folding, and the topographic maps may be used to show such folding. In a country of large and complex folding, the topographic contours may show the structures very plainly (Fig. 45), the danger is in mistaking the proper correlation of the outcropping formations. It is possible that a suitable dome may be found, but due to strong folding the oil- or gas-bearing horizons may have been brought to the surface and eroded. This applies only where the absence of other sands below the eroded ones is known.

Massive sandstones and limestones (hard strata) may form prominent escarpments or hog-backs, running parallel to the strike of the rocks, which generally are due to regularly dipping beds, and might have been eroded by streams running in the direction of the strike. Such a topography has a "stair-step"



Vertical section along lower edge of map.



Dotted line, profile of surface. Heavy line, profile of structure.

FIG. 45.—Effect of Folding upon Topography. Chestnut Ridge anticline forming a prominent ridge. A valley-like depression is caused by erosion along the anticlinal axis. (Map from Connellsville (Pa.) folio, U. S. G. S.)

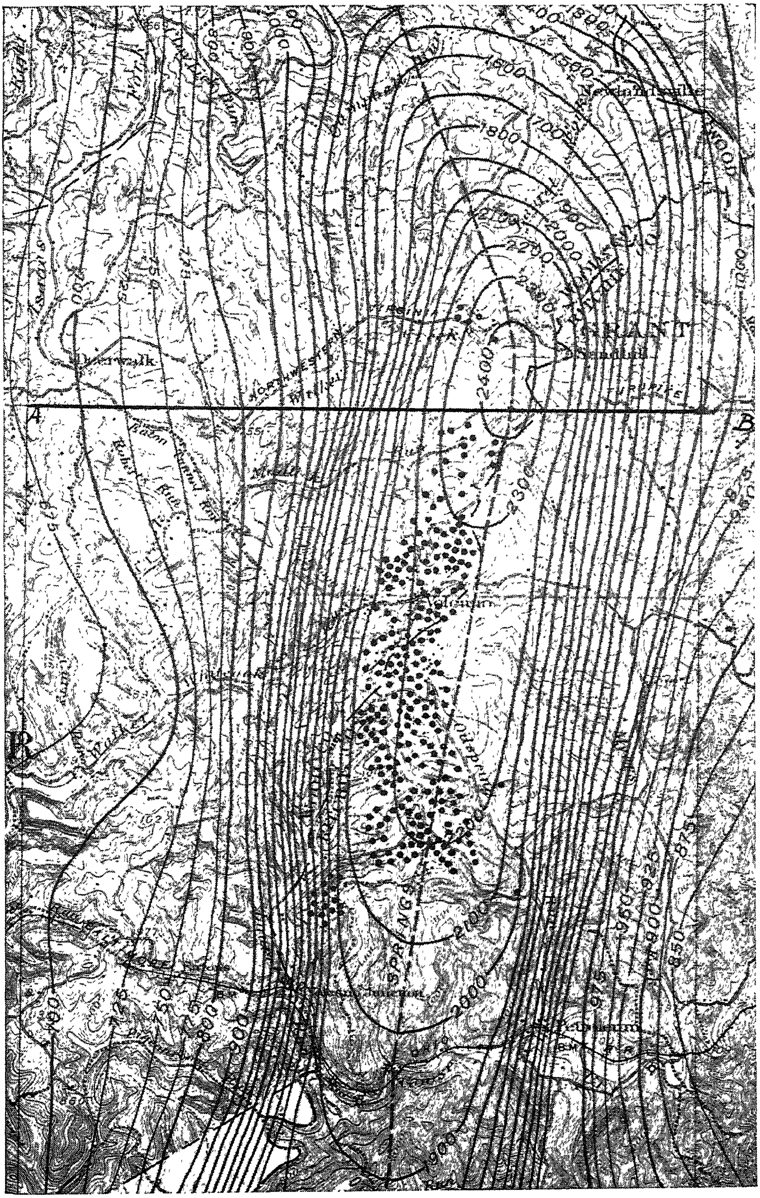


FIG. 461.—Isobath Map of the Burning Springs Anticline (W. Va.) This is one of the most pronounced producing structures in the Appalachian fields. (From W. Va. State Geol. Survey.)

appearance and clearly indicates the regional dip of the strata. When the dips are to the west, the steepest escarpments are on the east side of the hills, having the west slope or dip slope, rather gentle. Wherever the master dip, or main dip, is interrupted by a dip in the opposite direction, known as a "reversal," a fold is present. Thus if the direction of the main dip over a large territory be known, it is possible to find the reversals by working in the direction of the master dip. Reversals or dip

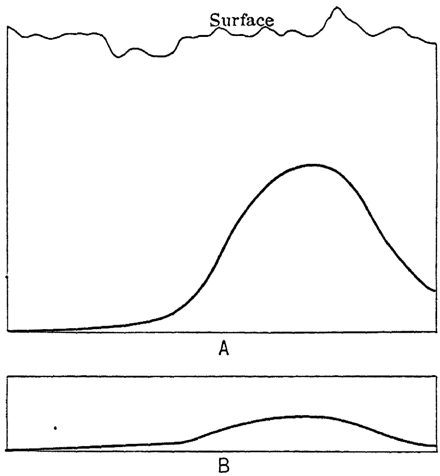


FIG. 46*b*.—East and West Section Across Highest Part of Burning Springs Anticline (W. Va.)

Section along line *AB*, Fig. 46*a*: *A*, horizontal scale $\frac{1}{2}'' = 5.280'$; vertical scale $\frac{1}{2}'' = 500'$; *B*, horizontal and vertical scales being equal, $\frac{1}{2}'' = 5.280'$. Notice the effect when the horizontal and vertical scales are different.

slopes are sometimes to one side (the reverse side) of the anticline, the axis showing weathered knobs, flat-topped mesas and buttes, or other characteristic forms along small dips. Where the dips affect the topography of a country, they are of the larger kind, and in a territory where the dips are small (15 to 30 feet per mile) less dependence should be placed on topographic features, as the arrangement and slopes of existing hills may or may not have been caused by the dip of the beds. In such cases the actual instrumental survey is the only safe method by which attitudes may be observed. (Fig. 46*a-b*.)

Areal geology maps may give some clue as to existing conditions. Where older rocks are surrounded by younger ones (Fig. 47) it may indicate the presence of a fold (and sometimes a fault). Should a stream originating in the younger rocks cut across the older ones then to the younger ones, the presence of

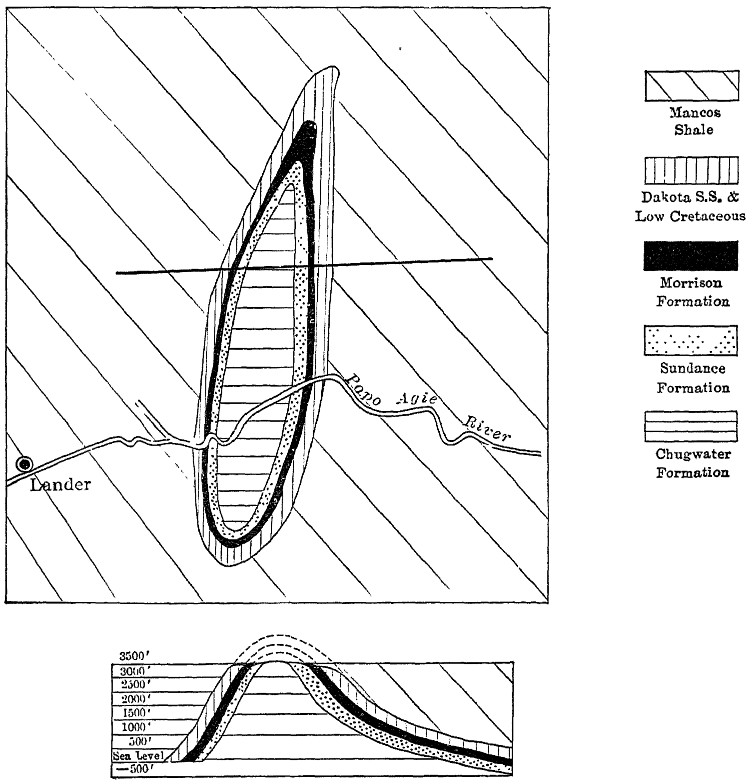


FIG. 47.—Anticlinal Structure Indicated by Younger Rocks Surrounding Older Ones, at Lander, Wyo.

an anticline is plainly indicated. If the conditions are reversed, i.e., if a stream originates in older strata, then flows through younger ones, then back to older ones, a synclinal structure is present. (Fig. 48.) It is also possible that when younger rocks are surrounded by older ones, the presence of such a condition

is due to erosion which has left the younger rocks as outliers. (Fig. 49.) Similarly inliers may be formed by erosion, causing older rocks to be surrounded by younger ones. A rapid succession of strata in regular order from older to younger or vice versa indicates a plane-dipping homocline, and will show the direction of the master dip of the territory.

A plunging anticline or syncline running parallel to the master dip will have a V-shaped appearance on an areal geology map. (Fig. 50.)

Folds and faults indicated by such methods are the larger

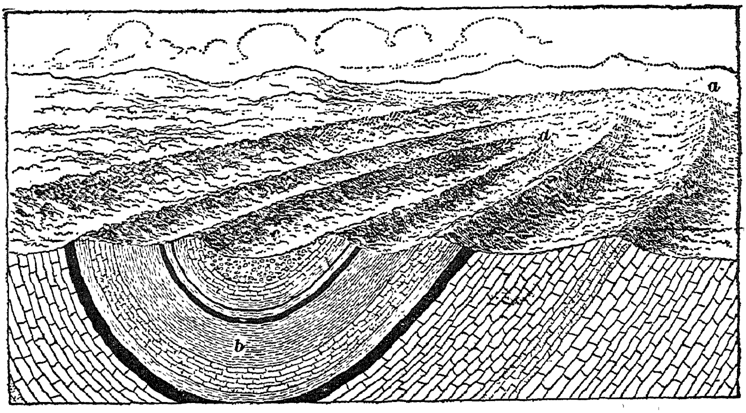


FIG. 48.—Synclinal Structure. (After Willis.)

ones, and it is possible that any of these structures may be present without a corresponding clue in areal geology maps. It is only in exceptional cases where small structures may be determined from such maps. A valley may be running along an anticlinal axis, or the reverse may be true, where the anticlinal axis may give rise to a ridge.

In the gulf coast country, the presence of salt-domes, which are the producing structures, gives rise to small knobs or elevations that may be plainly seen. However, many such domes are not so indicated.

It is sometimes possible to plot the mapped horizon on a topographic map and the dips calculated by the "cutting-across-

contours" of certain beds. Coal seams or limestones are best used in this connection. This method is simply the determining of elevations of the chosen horizon by the topographic contour lines, and a map so obtained may give some clue to various structures.

In a country where workable coal seams exist, but owing to

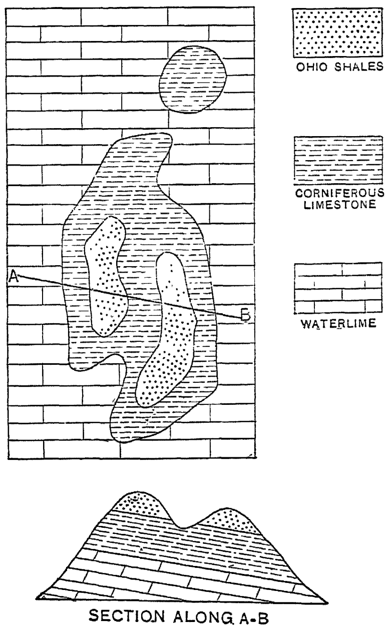


FIG. 49.

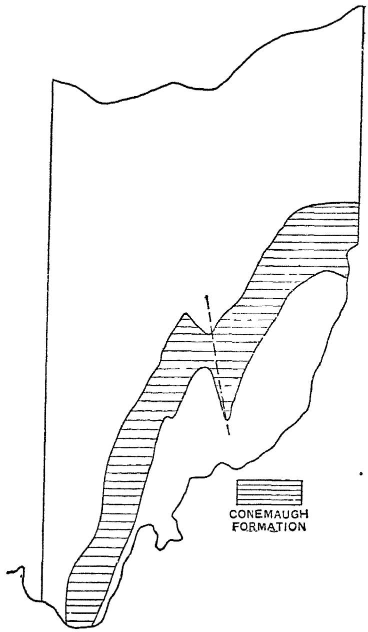


FIG. 50.

FIG. 49.—Outlier Caused by Erosion, "Bellefontaine Outlier," Northwestern Ohio.

FIG. 50.—Outcrop of the Conemaugh Formation in Eastern Ohio. (After D. Dale Condit.) Note the effect of the plunging Cambridge anticline crossing the formation along the dotted line, causing a V-shaped bend.

the fact that means of transportation are not handy such coals are not mined on a large scale, it is nevertheless common for many small country coal banks to be mined by the land-owners themselves for their own use. The drifts or openings for such mines are generally driven up the dip, so as to prevent the accumulation or water in the coal bank; as drifts driven down dip will

accumulate water, necessitating the use of pumps or siphons, as well as hauling the coal out of the mine against gravity.

The last resort is to map the structure carefully in the field with the use of the proper instruments. The general method is by determining the elevation of one or more key-horizons at many points. The success of such a work depends upon the exposures available, and their proper identification. By a key-horizon is meant any stratum that may be followed from place to place, or from outcrop to outcrop. If such outcrops are not continuous but are some distance apart, they may be identified by some characteristic peculiar to such a rock. Fossils offer the best and surest means of recognizing horizons, and therefore thin fossiliferous limestones make the best key-horizons. The columnar sections that are to be constantly made may show up some similarity by means of which a stratum may be identified. Lithology, or the character of the rocks, may be such as to be of value in this connection, however, only to a small extent, especially in the case of shales and sandstones, as they may change from one to the other within a short distance. Thus, a sandstone found in one hill may take the phase of a shale in the next, and if this is not recognized it may mislead one in the interpretation of the columnar section. The topographic terraces caused by resistant strata may be followed if no other means are possible. Coals make very good key-horizons, but where many coal beds are found, care must be taken not to confuse them. The shale partings in a coal bed may be such as to be of use in recognizing that particular seam. Prominent sandstone ledges may be followed and used as horizon markers, but must be handled carefully.

In following outcrops, it is possible to find some clue to them even when they are under cover; thus many coal seams, limestones and sandstones may have a spring issuing forth, and as the springs may be from a certain horizon, they may be used to some extent if carefully handled to find the outcrop of the formation. Again, many strata do not support vegetation and therefore the surface along them will be barren and cut up, giving the appearance of "bad-lands" on a small scale. A peculiar

color of shale, if known to be above or below a key-horizon, may assist in finding the stratum looked for, and may indicate the points to be searched.

The methods of obtaining the elevations of the various key-horizons are by means of the aneroid barometer, engineer's spirit level, transit stadia and plane table. The results obtained by the use of the aneroid are subject to the limitations of the instrument, and it is best adapted to a country that has many established bench marks, and where the outcrops are some distance apart; its advantage is the rapidity with which it may be completed, but folds so mapped are shown only in a general way, as the smaller variations of the contour lines cannot be obtained by such means.

Where good topographic maps are available so that the position of outcrops may be easily determined and indicated on the map, and where only one key-horizon is followed, the engineer's spirit level may be used to good advantage. Starting at a B.M. the elevation of the nearest outcrop is obtained, and the level is kept at that horizon and the rock followed from place to place along that contour, which will also assist in finding the outcrops as the elevation is being carried along.

Under similar conditions, but where more than one "marker" is used, the transit stadia is a dependable and fast method that may be employed. The use of this method enables the geologist to follow his key-horizons through all kinds of conditions; and he may easily change from the stadia to the spirit level method. It is of great value in a wooded country where numerous "set-ups" are required.

Attention is called to mistakes that may be caused by the changing from the stadia method to the spirit level. The stadia measurements are generally figured from the ground, and if the method is changed, the proper allowance is to be made for the height of the instrument, of the spirit level. For example: If a change is made from the level to the stadia, and if the last "shot" was a back sight, it will be necessary to subtract the height of the instrument above the ground, from the height of the instrument above sea-level, which is the last computation

in the notebook; and vice versa, when changing from stadia to the spirit level method, and if the next sight is to be a fore-sight, it will be necessary to add to the ground elevation the height of the instrument above the ground to obtain the H.I. above sea-level before such a fore-sight may be taken. (Fig. 24.)

The plane table is used to best advantage when a topographic map is not obtainable, as by use of it, both topographic and geologic maps may be made simultaneously. The plane table is at a disadvantage in a wooded country, where numerous set-ups are necessary. It is advisable that a note-book should also be used in connection with the plane table.

The plane table is by far the most important instrument for the geologist and it is most frequently used in all kinds of geological work; both the results obtained and the time and expense connected with it are its main features. The main points in its favor are that the outcrops and their elevations as well as all topographic details may be obtained and mapped right in the field so that the actual construction of the map in the field may show errors, which may be eliminated, such errors if obtained only in the office when the field notes are worked up would necessitate an extra trip back in the field. No cumbersome notes are kept and the calculations are eliminated. Horizontal angles are not read and recorded but plotted on the map. Any necessary sketching is done at once and not made from memory, so the details themselves may serve as models which in office work would not be obtainable. The limit within which the survey closes both as to horizontal and vertical measurements will be evident whenever a check reading is taken on various known points, thus a check on the work is had at all times. By means of it maps may be made to any convenient scale directly and economically and it is by far the most suitable instrument for the geologist and if properly handled it is a guarantee against inferior results.

It is customary for the geologist to carry the rod so that he may pick the proper outcrops and continually examine them, while the surveyor at the table may give all his attention to the mapping; otherwise, if the geologist were at the instrument and

a rod man used, the geologist would not only have to attend to the instrumental work, but would quite often be compelled to leave it to attend to the geological features which may need his attention.

Regardless of what system of geological surveying is employed, it is always necessary that all surveys should be closed or checked. The vertical distances are the most important in this connection and therefore in all cases either the original bench mark should be used or the survey closed at another bench mark, so that a check on the correctness of the work may be had.

During the progress of the field work care must be taken and many columnar sections made throughout, so that the several key-horizons may be reduced to a common one; also lateral variations be noted and its general direction and extent determined. Do not hesitate to go back to any point where certain possibilities may offer themselves; if you are in doubt as to the correlation of a formation, stay with it until you solve it. The work may progress along smoothly for days then something may occur that will hold up the work, but it is better that you be sure of your formations and the general geology, than to make a hasty guess which might involve serious errors. Remember there is no need for any guessing to be done, the geological work in the field must be absolutely correct in accordance with the highest standards.

When in search of a rock in particular, the farm owners may be able to lead you to the very place. They may not have the same name for it that the geologist uses, but they are usually observing and are well acquainted with their immediate vicinity and the peculiar rocks around there, and they may save you time. They are generally acquainted with the "fossil-rocks" and coal beds, and may be able to point them out to you where you least expected to find them. Another point in this connection that bears watching is this, be sure that the formation you find is *in place*, watch out for land slips that may have dislocated the rocks from their original position. Exposures found along roads are to be carefully watched, and wherever possible search should be made in the fields, up gullies and ravines. Road and railroad

cuts offer many good exposures, creeks should be followed, but exposures found in them are to be in place, and not merely found lying in the creek bottom. The geologist must do some clear thinking which in connection with his instrumental observations will bring good results.

Be on guard against false dips. Quite often a stratum deposited by strong currents is made up of inclined layers (cross beds) having the appearance of bedding planes which may be taken for dip. They are most often found in sandstones. (Fig. 51.)

Contemporaneous erosion may also mislead one in this same way. This is caused by a current of water forming a channel during sedimentation, and when such a flow has stopped, the

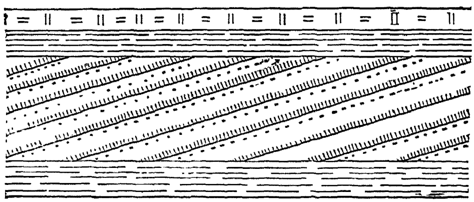


FIG. 51.—Cross Bedding or False Dip.

excavated channel may be filled up resulting in an irregular line having a synclinal appearance. (Fig. 52.)

The methods of obtaining dips in a territory where the dips may easily be seen with the naked eye is done by means of a clinometer and magnetic needle. Such instruments may be combined in one, such as the Brunton pocket transit. It is best to make clinometer measurement at points where the outcrop may be seen for a considerable distance, and then the true dip sighted with the clinometer in hand, at the upper or lower portion of the outcrop and sighted to the furthest visible portion of it.

Never pass up any wells that have been drilled in a territory in which you are working; and by all means try to get all the information possible about them. Locate them on the map and

get the elevation of the ground, as well as the elevation of the top of the casing if there is one sticking out of the hole; as the measurements of the depths of wells are done from the derrick floor, which is generally on level with the top portion of the casing.

Seepages. In the course of field work one should always be

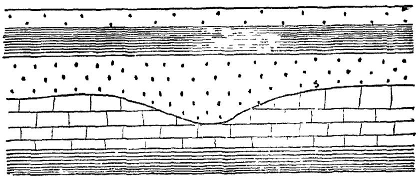


FIG. 52*a*.—Contemporaneous Erosion.

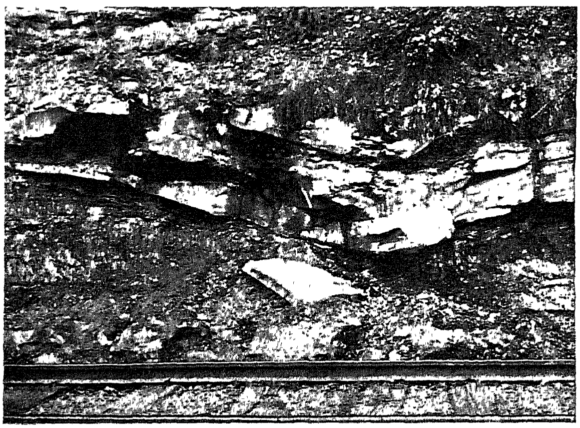


FIG. 52*b*.—Contemporaneous Erosion Effecting Coal and Allowing Sandstone to Replace Upper Part of Coal.

Coal at left 43 inches thick; at center 14 inches; at latter point the upper bench of coal, 1 foot thick, has been entirely removed. (Geol. Surv. of Penna. Report, 1906–1908. Photo by G. H. A.)

on the lookout for seepages of oil and gas. In a country not previously prospected, and where the geological horizons are not well known, seepages are of great value in determining the possible oil- and gas-bearing horizons. Seepages may be either at the outcrop of the strata or may be at a fault, and thus in

each case the condition under which a seepage is found should be determined. Seepage may be from shale, and is therefore important only in determining the possible source from which oil may migrate into a suitable reservoir. A seepage at the outcrop might indicate that the stratum is petroliferous, and in following the stratum down the dip away from the point of seepage and under good structure it may become a good prospect.

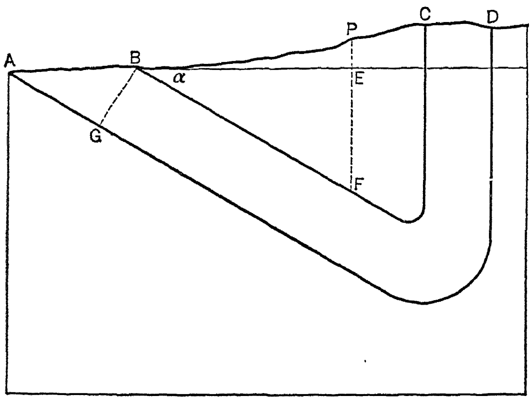


FIG. 53.

	Formulæ.
To find thickness of stratum when distance *AB* and angle at *A* (α) are known. (*BG* unknown.)	$BG = AB \sin \alpha$
To find depth of stratum under cover at point *P* when distance *BE* and angle of dip are known. *PE* is obtained by leveling between *B* and *P*. (*EF* unknown.)	$EF = BE \tan \alpha$ $EF + PE =$ total depth.
To find dip of stratum, when *PF*, *BE* and *PE* are known. (Angle *EBF* (α) unknown dip.)	$PF - PE = EF$ $\frac{EF}{BE} = \tan \alpha$

NOTE.—If *P* is lower than *B*, the algebraic sign of *PE* is the opposite to that given above. In a general formula *PE* should be shown as plus or minus ($\pm$).

If the outcrop is well sealed by the residue of evaporated oil, the latter may be found close to the outcrop. A change in the lithological character of a rock may also permit accumulations a short distance away. There are a great many pools so located, near the outcrop, and although generally small, yet are commercially valuable, as they are shallow and therefore not expensive to operate. Outcropping sands may be analyzed to determine the presence of oil, by treating a crushed sample with ether;

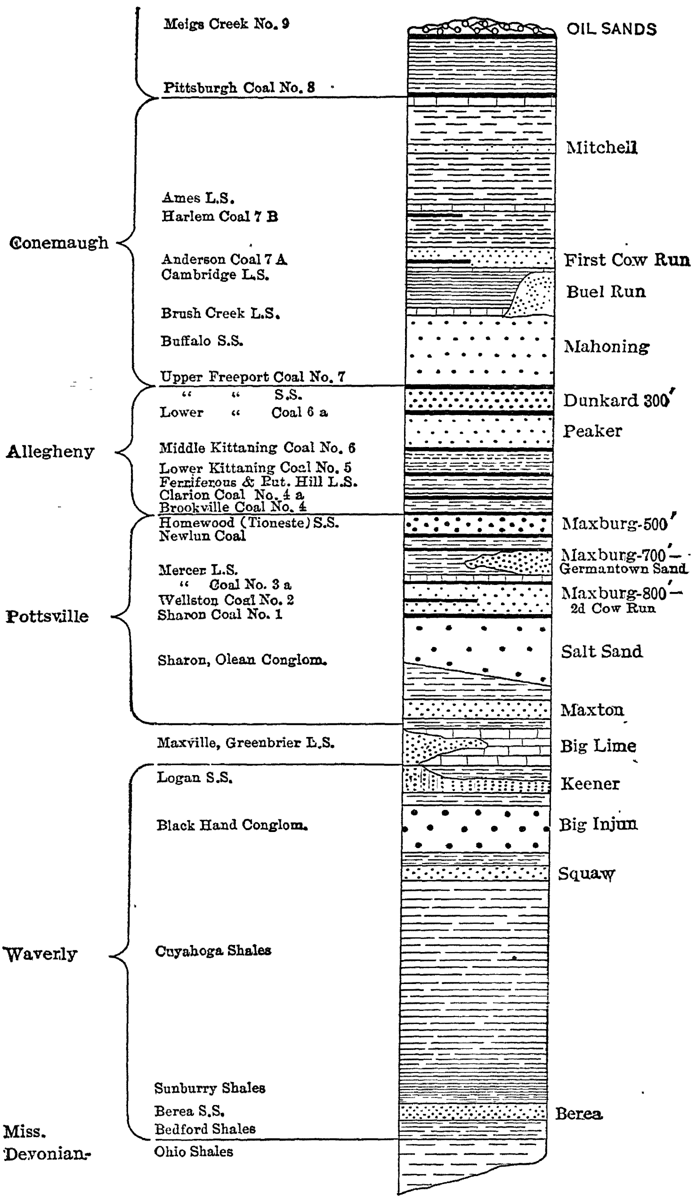
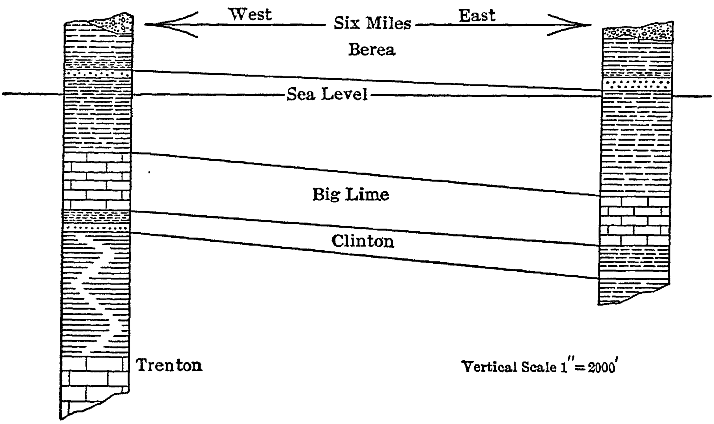


FIG. 54.—Generalized Section of Southeastern Ohio, Showing Carboniferous Oil Sands.
Vertical scale 1 inch = 300 feet.

the hydrocarbons, if present, will be in solution, which upon evaporation will show an oil ring as a residue. Dark and black color will indicate an oil containing asphalt for a base and a light color indicates paraffin.

Do not be misled by floating of iron stain upon water. To the casual observer it is similar to a film of oil, but it is only iridescent films of iron hydroxide. The two may be distinguished simply by disturbing the film, and if it is iron stain it will break



"Big Injun" and Waverly shales	In surface outcrops
Berea Sandstone	20 to 80 ft. thick
Bedford (Carboniferous) and Ohio (Devonian)	750 to 900 ft. thick
"Big Lime" (Corniferous and Niagara)	570 to 675 ft. thick
Interval "Big Lime" to "Clinton"	175 to 210 ft.
Interval "Clinton" to Trenton	1,350 ft. (estimated)

FIG. 55.—Generalized Section of Central Ohio. (L. S. Panyity in Transactions of the Am. Inst. of Mining Engineers. Vol. LVII, p. 984.)

into irregular pieces, but in case of oil it will make round patches and will easily "run-together" again. Many useless oil excitements have been caused by the finding of such an "oil" seep.

Depth and Thickness of Strata. In a country where the dips are moderate, the outcrop of a thick stratum cutting a horizontal plane will give a rather exaggerated idea of the thickness of that formation. (Fig. 53.) In order that the true thickness may be known, it is to be calculated by means of trigonometrical formulæ. This may be done by considering the distance of the

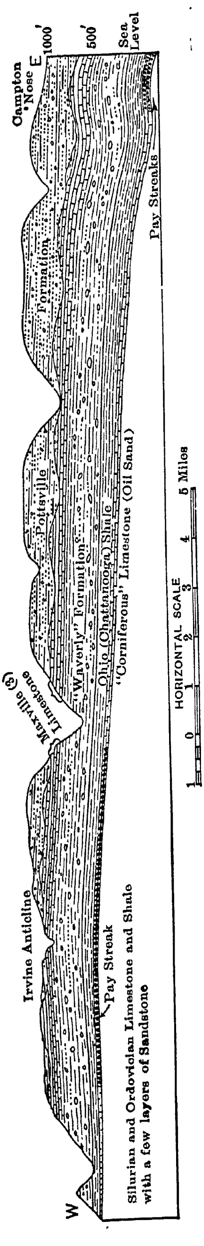


FIG. 56.—Cross-section from Irvine to Campton, Ky., Showing the Dip and Thickening of Formations in that Direction, the structural features on which the oil pools are found, and the general attitude of the surface. (U. S. G. S. Bul. 661-D.)

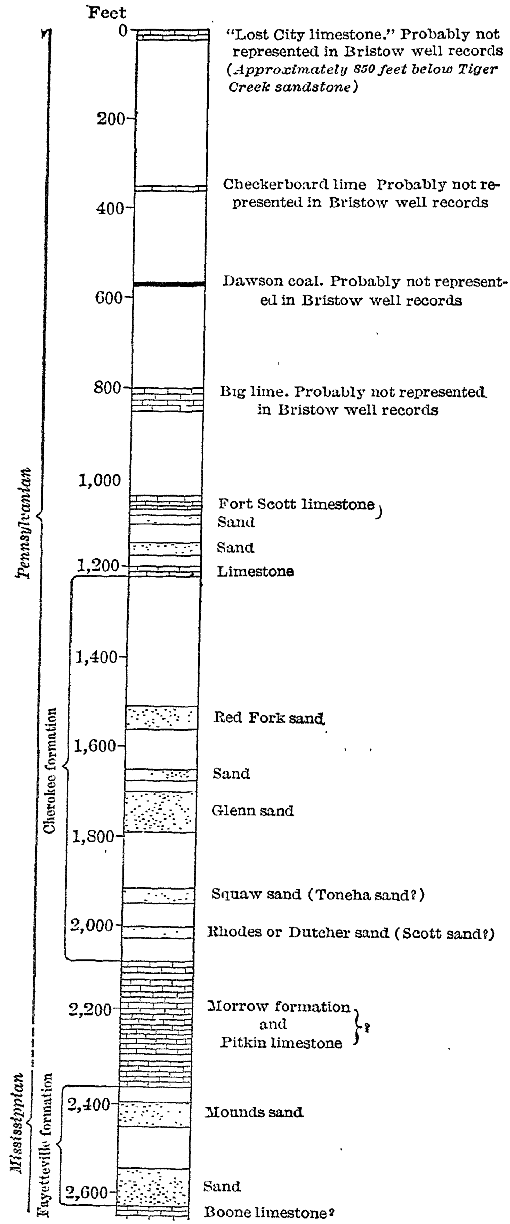


FIG. 57.—Composite Skeleton Stratigraphic Section of the Glenn Pool Region. Oklahoma. (U. S. G. S. Bulletin 661-B.)

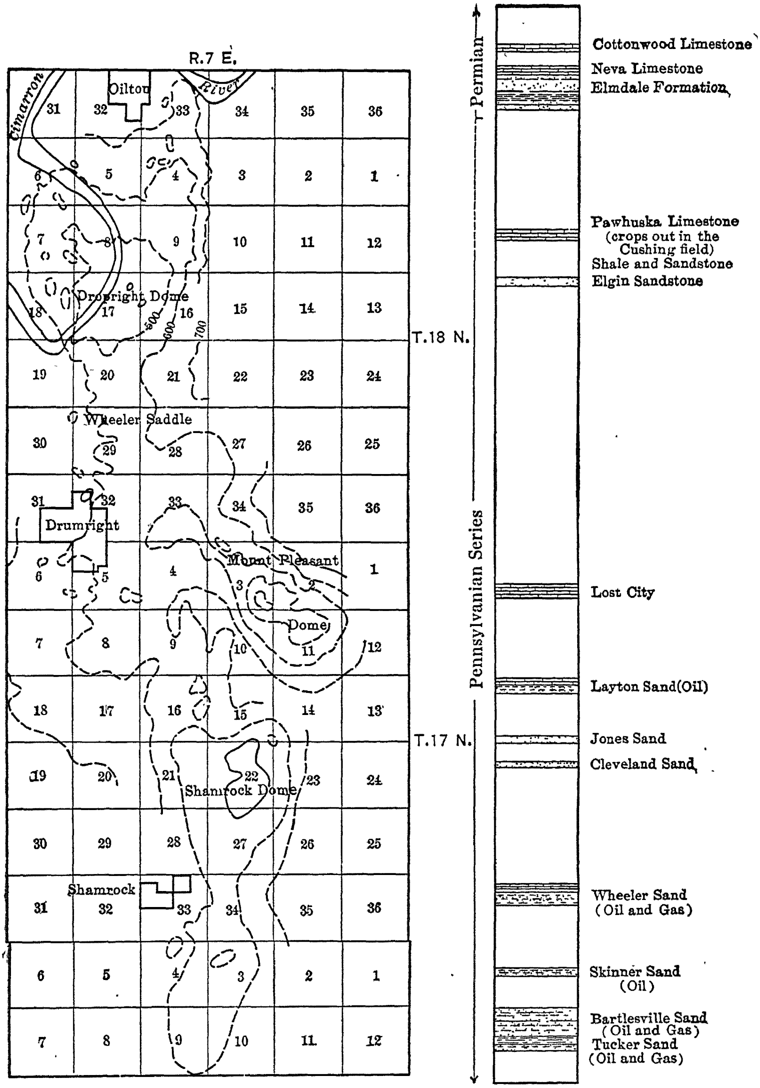
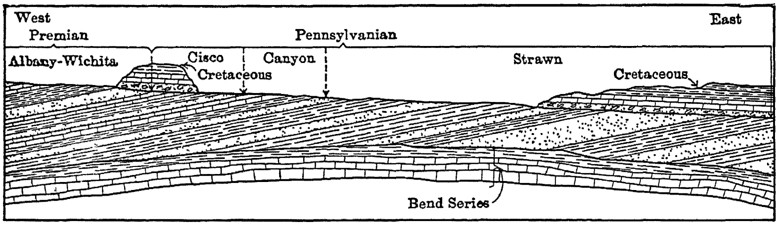


FIG. 58.—Sketch Map of Cushing (Okla.) Field, showing generalized structure of Layton Sand and location of principal structural features. Contour interval is 100 ft. Also, composite columnar section showing relative vertical positions of productive oil sands in the Cushing field and some of the better known formations in Kansas and Oklahoma. (C. H. Beal, in Bulletin 128 of the Am. Inst. of Mining Engineers.)

outcrop along the horizontal plane as the hypothenuse of a right-angled triangle, the angle of dip being known, it is a simple matter to figure the thickness of that stratum. Similarly, when the distance below the ground a stratum may be expected, it is to be figured by trigonometry, the dip being known as well as the distance along the surface from the outcrop. In order



				Thickness, feet
Mesozoic	Cretaceous	Comanche beds	Sandstone, shales, limestones	200–500
	Permian	Albany—Wichita	Principally limestones, shales	1200
Carboniferous	Pennsylvanian	Cisco Canyon Strawn	Limestones, shales Shales, limestones Principally shales, sandstones	900 600–800 2500–4000
	Mississippian	Bend series, 800–1000 ft.	Smithwick shale Marble Falls limestone Lower Bend shale	400 450 50

FIG. 59.—Stratigraphy of North Central Texas. (Dorsey Hager in Bulletin 138, Am. Inst. of Mining Engineers.)

that the unevenness of the surface may be accounted for the elevation of the outcrop as well as the elevation of the point where the depth of the strata is wanted should be known. A simple method of using alignment diagrams is given by Mr. Harold S. Palmer, in the U. S. G. S. Professional Paper No. 120-G, by means of which the depth of the stratum, the thickness of the stratum, as well as its projected dip may be determined by the application of these diagrams.

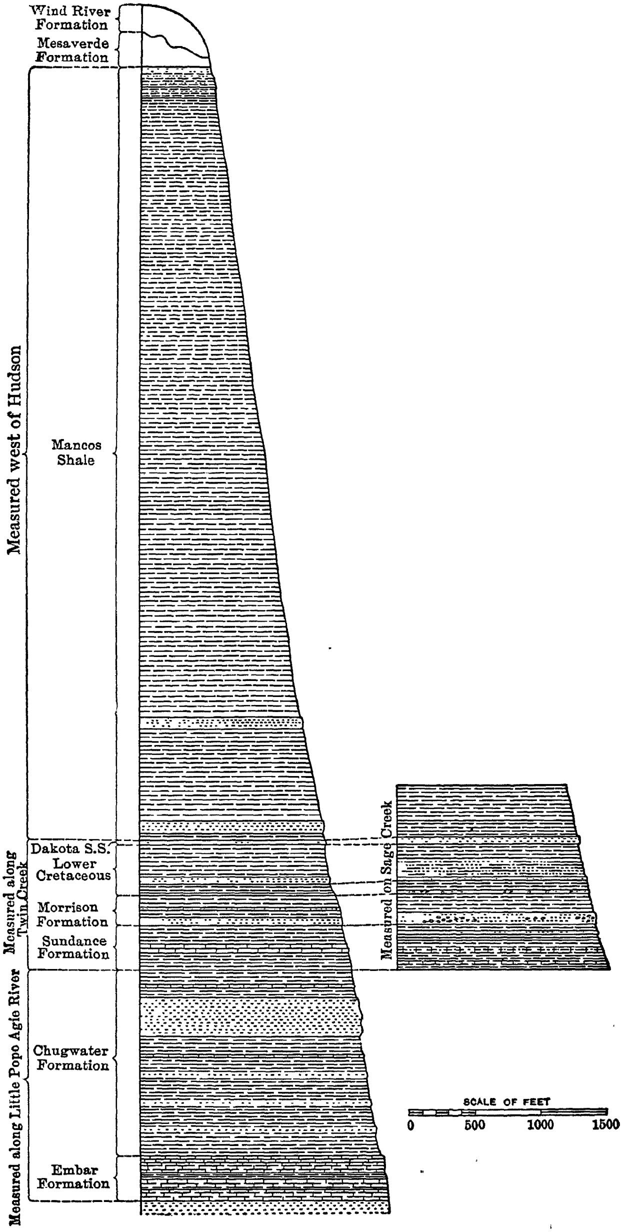


FIG. 60.—Columnar Section in Lander Oil Field, Wyoming. (U. S. G. S. Bulletin 452.)

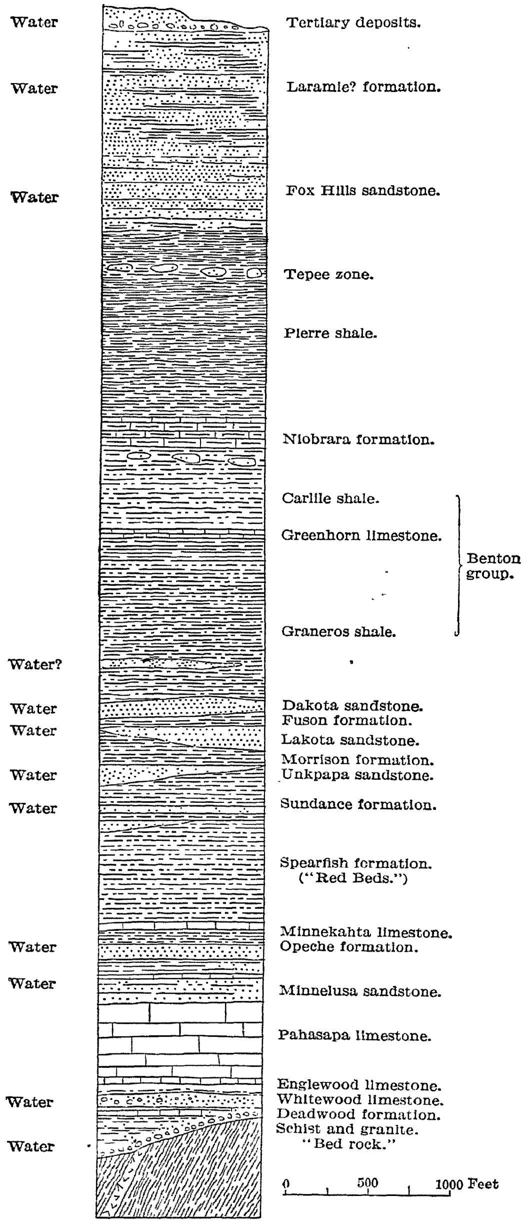


FIG. 61.—Columnar Section of Sedimentary Formations in the Northern Black Hills Region, Showing Water-bearing Beds. (U. S. G. S. Professional Papers No. 65.)

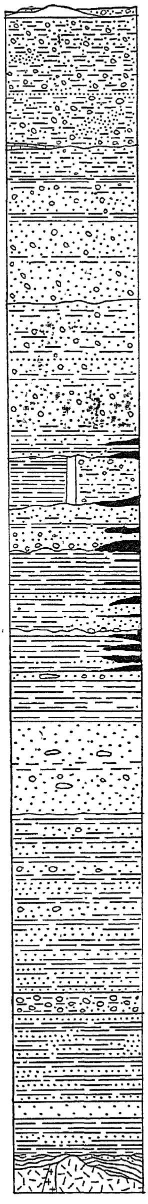


FIG. 62.—Generalized Columnar Section of the Sedimentary Rocks of the Coalinga District. Oil zones shown in solid black. (U. S. G. S. Bulletin 398.)

Diagram showing structure and stratigraphy of anticline in Little Popo Agie district.

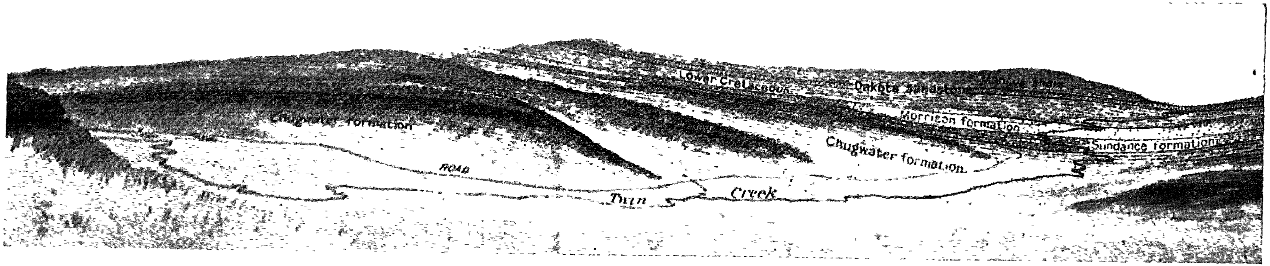


FIG. 63.—View of Anticline in Little Popo Agie District, Lander Oil Field, Looking Northwest Across Twin Creek. (U. S. G. S. Bulletin 452.)

CHAPTER X

FOSSILS

FOSSILS are essentially the remains of animals and plants, that existed during the various geologic ages, and are found to-day buried in the sediments. In this connection we may add, that in a strict sense, almost anything found in any state of preservation in the rocks, may be considered as fossils; thus footprints of animals, tracks of worms and mollusks, as well as burrows of various creatures, if properly preserved are considered as fossils.

From the beginning, animals and plants have been undergoing a great change, from a lower to a higher order, increasing and improving in their structure and form. It is known that animals and plants as a species live for a limited time, then become extinct, and new species are formed, so it is established that certain groups did not extend beyond a certain geologic time; thus it becomes possible to use these remains of organism that we find embedded in the rocks and study the life that existed during the time of the formation of the stratum. As certain characteristic remains may be found in the various strata, they are used as "index fossils," as they indicate the life of a certain geologic period. By use of these fossils the geologist is enabled to correlate widely separated rocks, and prove that they are of the same age, and in many cases it is confirmed that they are portions of the same stratum.

The hard or bony parts of animals and plants are preserved as fossils, therefore, the very earliest of living creatures that had no hard parts are not well known to us as fossils, and the first class of organism with which we become acquainted in the Cambrian (the Trilobites) are considerably advanced in structure and form.

In Paleontology two separate groups are distinguished, firs the plant group (flora) and secondly the animal group (fauna), an each are in turn divided in smaller groups known as divisions o phyla. Each division and phylum is composed of animals o plants which are genetically connected.

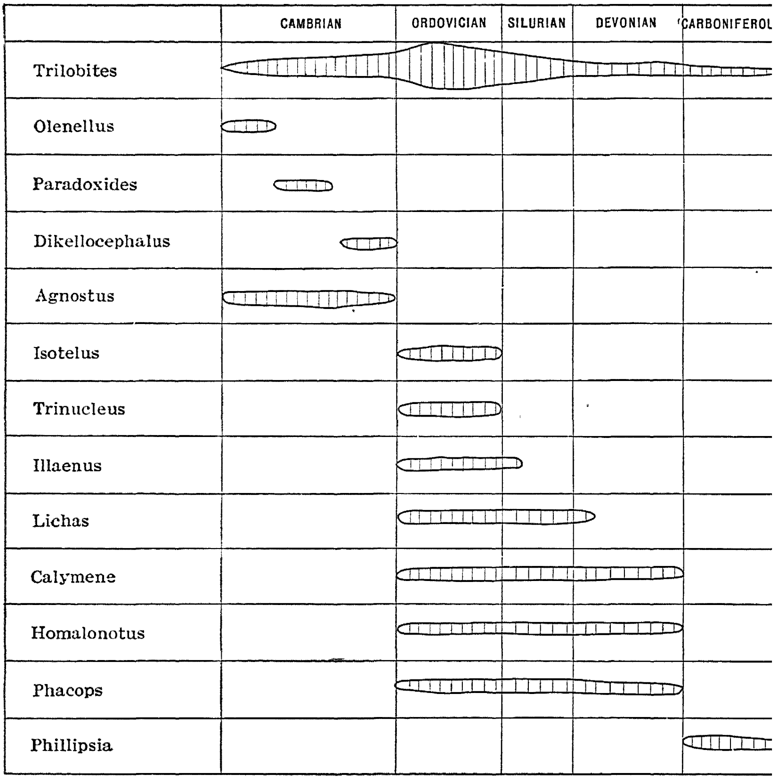


TABLE II.—Range of several *families* of trilobites, which may be further subdivided into *genera* and *species* to show the range of smaller interval of time for which they may be indices.

FLORA

DIV. I. THALLOPHYTA

1. Algæ
2. Fungi

DIV. II. BRYOPHYTA
- 1. Moss

DIV. III. PTERIDOPHYTA
- 1. Cryptogams
- 2. Equisatelas
  - *Calamites* (Carboniferous)
  - *Lepidodendron* (Low. Dev. to Permian)

DIV. IV. SPERMATOPHYTA
- 1. Gymnospermæ
- 2. Angiospermæ

FAUNA

PHYLUM I. PROTOZOA
- *A*. Sarcodina
  - 1. Rhizopoda (Foraminifera)
    - *Globigerina*
    - *Nummulites*
  - 2. Actinopoda (Radiolaria)
- *B*. Mastigophora
- *C*. Sporozoa
- *D*. Infusoria

PHYLUM II. PORIFERA
- *A*. Calcispongiæ
- *B*. Silicispongiæ

PHYLUM III. COELENTERATA
- *A*. Hydrozoa
  - *Phyllograptus*
  - *Monograptus*
- *B*. Scyphozoa (Jelly fish)
- *C*. Anthozoa
  - *Columnaria*
  - *Favosites*
  - *Halysites*

PHYLUM IV. PLATYHELMINTHES (Flat worms)

PHYLUM V. NEMATHELMINTHES (Thread worms)

PHYLUM VI. TROCHELMINTHES (Wheel worms)

PHYLUM VII. ANNULATA (Ring worms)

PHYLUM VIII. ECHINODERMATA

A. Cystoidea

Caryocrinus

Agelacrinus

B. Blastoidea

Pentremites

C. Crinoidea

Pentacrinus

D. Asteroidea

Paleaster

E. Ophiuroidea

F. Echinoidea

G. Holothurioidea

PHYLUM IX. MOLLUSCOIDEA

A. Bryozoa

Fenestella

Archimedes

B. Phorondia

C. Brachiopoda

Lingula

Strophomena

Leptæna

Productus

Platystrophia

Spirifier

PHYLUM X. MOLLUSCA

A. Amphineura

B. Pelecypoda

Ostrea

Inoceramus

Exogyra

Pecten

C. Gastropoda

Bellerophon

Turritella

Tentaculites

D. Scaphopoda

E. Cephalopoda

Orthoceras

Nautilus

Scaphites

Baculites

Belemnites

PHYLUM XI. ARTHROPODA

A. Crustacea

Olenellus

Paradoxides

Dikellocephalus

Agnostus

Isotelus

Trinucleus

Illænus

Lichas

Calymene

Homalonotus

Phacops

Phillipsia

B. Onychophora

C. Myriopoda

D. Arachnida

Eurypterus

E. Insecta

PHYLUM XII. CHORDATA (Vertebrates)

Sub-phylum I. Adelochorda

Sub-phylum II. Urochorda

Sub-phylum III. Vertebrata

1. Acrania
2. Craniata

Table III

GEOLOGICAL RANGE OF FOSSILS

Invertebrates.	Cambrian.	Ordovician.	Silurian.	Devonian.	Carbonif-erous.	Triassic.	Jurassic.	Cretaceous.	Tertiary.	Quater-nary.
Globigerina						*	*	*	*	*
Nummulites					*	*	*	*	*	*
Phyllograptus		*								
Monograptus			*							
Fenestella			*	*	*					
Archimedes					*					
Columnaria		*	*	*						
Halysites		*	*							
Favosites		*	*	*	*					
Caryocrinus		*	*							
Agelacrinus		*	*	*	*					
Pentremites					*					
Pentacrinus						*	*	*	*	*
Paleaster		*	*	*	*					
Lingula		*	*	*	*	*	*	*	*	*
Strophomena		*								
Leptaena		*	*	*	*					
Productus				*	*					
Platystrophia		*	*							
Spirifier			*	*	*					
Ostrea					*	*	*	*	*	*
Inoceramus							*	*		
Exogyra							*	*		
Pecten					*	*	*	*	*	*
Bellerophon		*	*	*	*					

TABLE III—*Continued*

INVERTEBRATES.	Cambrian.	Ordovician.	Silurian.	Devonian.	Carbonif-erous.	Triassic.	Jurassic.	Cretaceous.	Tetriary.	Quater-nary.
Turritella.........						*	*	*	*	*
Tentaculites......		*	*	*						
Orthoceras........		*	*	*	*	*				
Nautilus.........									*	*
Scaphites.........								*		
Baculites.........								*		
Belemnites.......							*	*		
Olenellus.........	*									
Paradoxides......	*									
Dikellocephalus...	*									
Agnostus.........	*									
Isotelus..........		*								
Trinucleus........		*								
Lichas...........		*	*	*						
Calymene........		*	*	*						
Homalonotus.....		*	*	*						
Phacops..........		*	*	*						
Phillipsia.........					*					
VERTEBRATES.										
Cyclostomata.....				*	*	*	*	*	*	*
Ostracodermi.....			*	*						
Pisces............			*	*	*	*	*	*	*	*
Amphibia........					*	*	*	*	*	*
Reptilia..........					*	*	*	*	*	*
Aves.............						*	*	*	*	*
Mammalia........						*	*	*	*	*

A. Cyclostomata
B. Ostracodermi
C. Pisces
D. Amphibia
E. Reptilia
F. Aves
G. Mammalia
  a. Monotremata
  b. Marsupialia
  c. Insectivora
  d. Chiroptera
  e. Carnivora
  f. Rodentia
  g. Edentata
  h. Ungulata
  i. Sirenia
  j. Cetacea
  k. Primates

DIVISION I. THALLOPHYTA

The most ancient plants, those with simple structure, such as slime molds, bacteria, diatoms and other microscopic one-celled plants, as well as algæ or primitive sea-weeds are in this division. Sea-weeds quite often assist in building coral-reefs by furnishing a large amount of the lime necessary. In this same class are also the fungi, of which toadstool, mushroom mold, mildew and yeast are familiar examples.

DIVISION II. BRYOPHYTA

The plants of this division are advanced over the Thallophyta, especially in their mode of reproduction. The mosses are the typical plants of this division. As the members of the two foregoing divisions are seldom found as fossils they are unimportant to the geologist.

DIVISION III. PTERIDOPHYTA

Although the members of this division bear no true flowers and seeds (cryptogams), they are much more complex than the aforesaid plants. The best preserved fossils of this division are ferns. Equisatelas (horse-tail) plants with simple stems, have been known from the Devonian to the present, but like most plants they were abundant during the Devonian and Carboniferous, when vegetation was immense, and are well preserved in the coal measures. Lepidodendron is the best known fossil tree of the Paleozoic.

DIVISION IV. SPERMATOPHYTA

Highly organized seed-producing plants are in this division, and have two subdivisions, namely—(1) Gymnospermæ or plants with seeds that are unprotected by any covering; evergreens and shrubs being typical of this subdivision. (2) Angiospermæ are the plants of the highest order, and all the flowering plants, and most of the present known species of the plant life come under this subhead.

PHYLUM I. PROTOZOA

Protozoa are simple one-celled, generally microscopic animals, consisting mainly of protoplasm, usually without hard parts, and therefore, without any fossil remains. Under the class of Sarcodina we have relatively large marine and fresh water Protozoa, some visible to the naked eye, and in the subclass Rhizopoda (most important in geology) we have creeping forms and some, like Foraminifera have a calcium carbonate skeleton or test, with one or more chambers. They are mostly marine animals living in water free from sediments, and in the Mississippian period, Foraminifera became important rock builders, and the chalk of the upper Cretaceous, namely, the Niobrara, Austin and Rotten limestone formations are composed of Foraminifera combined with members of other phyla which are known to be shallow water forms, thus indicating that Foraminifera lived in shallow water.

Foraminifera are known to have existed in the Ordovician, and were abundant in many Pennsylvanian limestones. Nummulites abounded in the Eocene limestones. Orbitoides, which formed the Vicksburg limestone, are known from the Cretaceous to the Miocene.

The subclass Actinopoda contains animals that depend on floating for locomotion. Radiolaria, the most important members of this class, are marine organisms, and when accumulating on sea bottom, form silicious deposits known as "radiolarian-

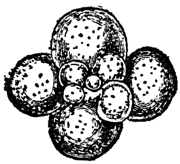


FIG. 64.—*Globigerina bulloides.* (After Williamson.)

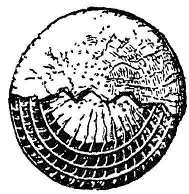


FIG. 65.—*Nummulina laevigata.* (After Le Conte.)

ooze" and became important rock builders in the Tertiary; traces of them are found in nearly all periods.

The other classes which are Mastigophora, Sporozoa and Infusoria are unimportant as fossils.

PHYLUM II. PORIFERA

The typical animals of the Porifera are the sponges, which are aquatic animals generally fixed to some object and found mostly in the shallow parts of the seas; only those having a silicious skeleton occur at great depth. Those having a calcareous skeleton are known as Calcispongiae, while those with a silicious test are Silicispongiae.

PHYLUM III. COELENTERATA

These are mostly marine animals with a body cavity which is the digestive organ. The mouth is surrounded by numerous tentacles. In the Hydrozoa subdivision are the polyps and medusae, with an important order of Graptolites, which are well

developed in the upper Cambrian, Ordovician and Silurian; only a few are known in the Mississippian. The class of Scyphozoa, in which are the jelly-fish composed mostly of water and have no hard parts, therefore, poorly preserved as fossils. The third class are the Anthozoa, or corals, which are found mostly in shallow seas, and at present may be found along the Atlantic, but not in the colder waters of the North.

PHYLA IV, V, VI, VII

In these phyla the fossils are poorly preserved and are unimportant in a geological sense.

PHYLUM VIII. ECHINODERMATA

Echinodermata are marine animals having a calcareous skeleton or plates generally arranged in fives (pentamerous), and

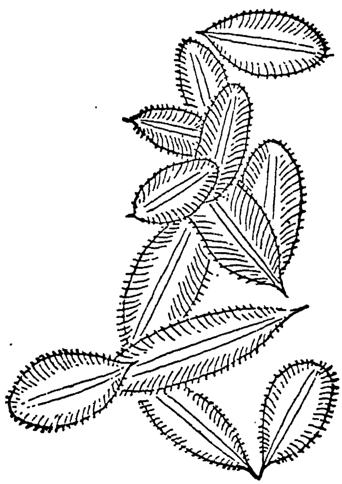


FIG. 66.—*Phyllograptus typus.* (After Hall.)

FIG. 67.—*Monograptus priodon.* (After Nicholson.)

may be distinguished from the Coelenterata as they have a digestive tube separate from the body cavity, and more highly developed nervous system. The various important classes are

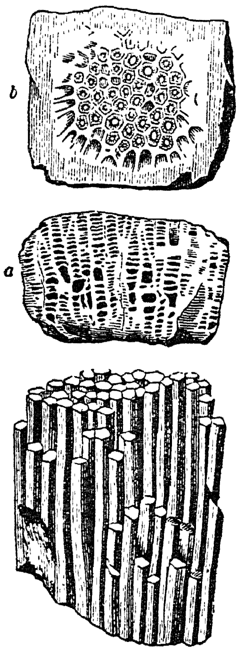


FIG. 68.—*Columnaria alveolata:* *a*, vertical; *b*, cross-section. (After Hall.)

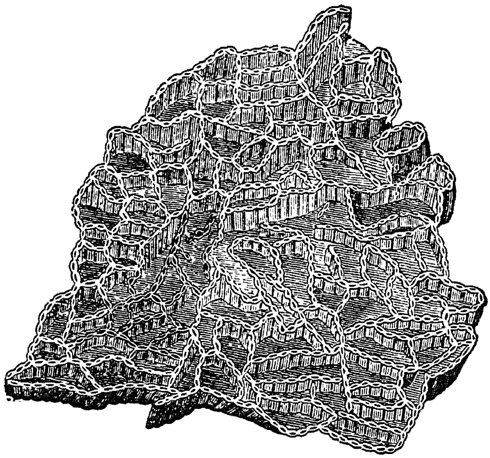


FIG. 69.—*Halysites catenulata.* (After Hall.)

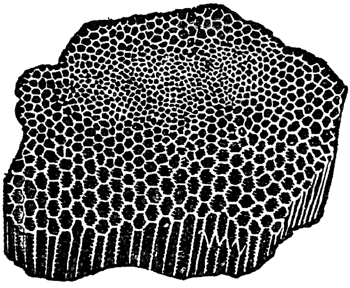


FIG. 70.—*Favosites hemispherica.* (After Le Conte.)

(A) Cystoidea or Cystoids, (B) Blastoidea or Sea-Buds, abundant in the Devonian and entirely extinct at the end of the Carboniferous; (C) Crinoidea or Sea-Lilies; (D) Asteroidea or

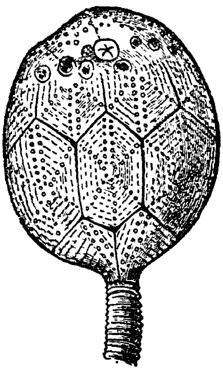


FIG. 71.—*Caryocrinus ornatus.* (After Le Conte.)

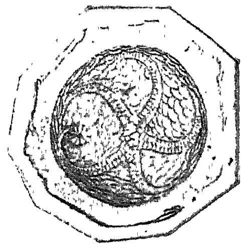


FIG. 72.—*Agelacrinites Cincinnatiensis.* (After Newberry.)

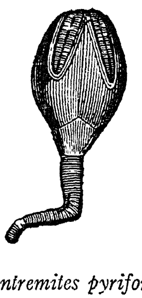


FIG. 73.—*Pentremites pyriformis.* (After Newberry.)

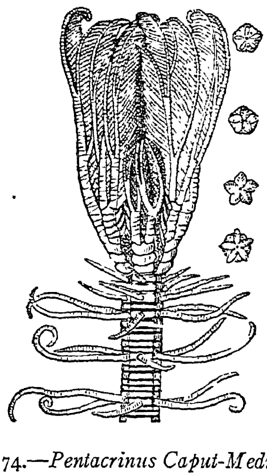


FIG. 74.—*Pentacrinus Caput-Medusæ.* (After Le Conte.)

Star-Fish; (E) Ophiuroidea or Brittle-Stars and Serpent Stars; (F) Echinoidea or Sea-Urchins; (G) Holothuridoidea or Sea-Cucumbers.

PHYLUM IX. MOLLUSCOIDEA

These are usually marine animals having their soft parts and well-developed digestive canal enclosed in a calcareous, horny or membranous covering.

The hard outer covering of the Bryozoa are the only parts found as fossils. Phoronida are wormlike marine animals

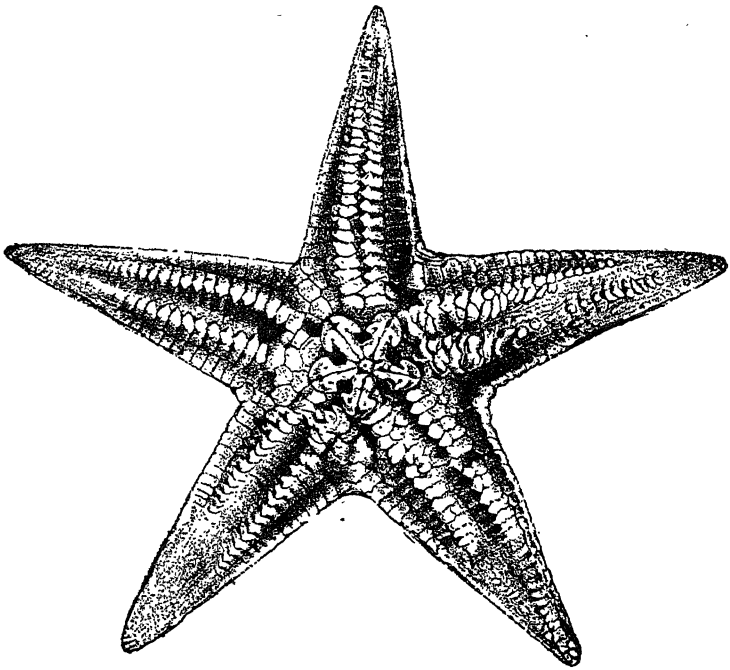


FIG. 75.—*Paleaster Jamesii.* (After Newberry.)

unknown in the fossil state. Brachiopods are found living in shallow water, having calcareous shells or valves with concentric lines of growth. Brachiopods may be distinguished from the Pelecypods (of the next phylum) as they are equilateral, while Pelecypods are inequilateral; in Brachiopods the two valves are never alike while in Pelecypods they are nearly or exactly alike. Brachiopods are about $\frac{1}{2}$ to $1\frac{1}{2}$ inches in size, although a few are much larger, and *Productus giganteas* of the Mississippian

sometimes reach one foot in size. Inarticulata of the Lingula subgroup are evidence of shallow water conditions as the shallow water forms are the most prolific in the fossil state.

PHYLUM X. MOLLUSCA

Mollusks are covered, shell animals able to swim, crawl and burrow; the various classes that are distinguished are the (A)

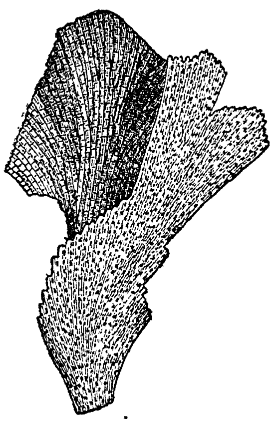


FIG. 76.—*Fenestella elegans.* (After Hall.)

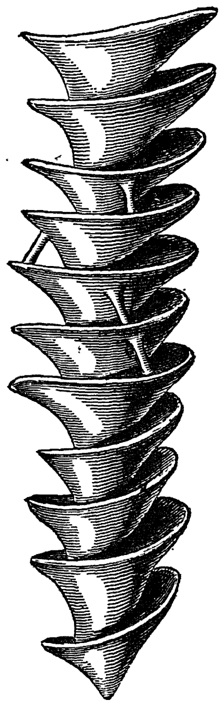


FIG. 77.—*Archimedes Wortheni.* (After Hall.)

Amphineura, which are marine animals with a wide range of depth. (B) Pelecypoda or clam group, sometimes classified as Lamellibranchs. (C) Gastropoda, the familiar snails are examples of this class. They have a rather large calcareous shell, with six whirls or coils at the posterior end and prolonged into a half cylindrical canal at the anterior end. The gastropods have a

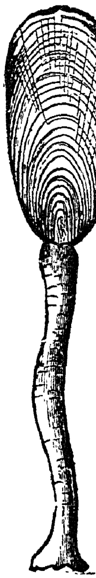


FIG. 78.—*Lingula anatina*, showing muscular peduncle by which the shell is attached. (After Le Conte.)

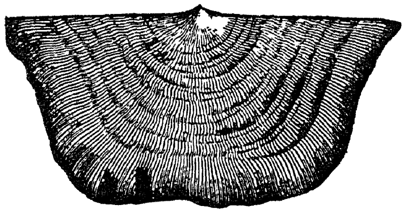


FIG. 79.—*Strophomena rhomboidalis*. (After Le Conte.)

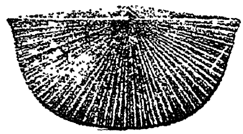


FIG. 80.—*Leptæna sericea*. (After Newberry.) Dorsal view.

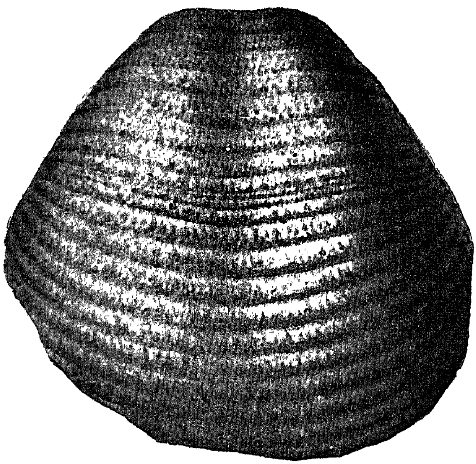


FIG. 81.—*Productus punctatus*.

distinct head as well as tentacles and eyes. (D) Scaphopoda have a calcareous shell, curved and tapering, the larger end being anterior, which has the head and feet but no eyes. They

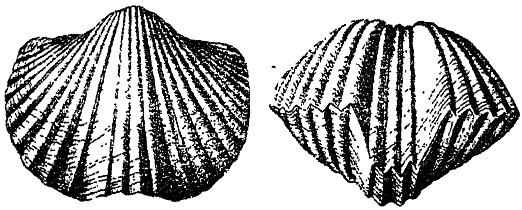


FIG. 82.—*Orthis* (*Platystrophia*) *biforata*. (After Newberry.)
Dorsal, anterior and ventral views.

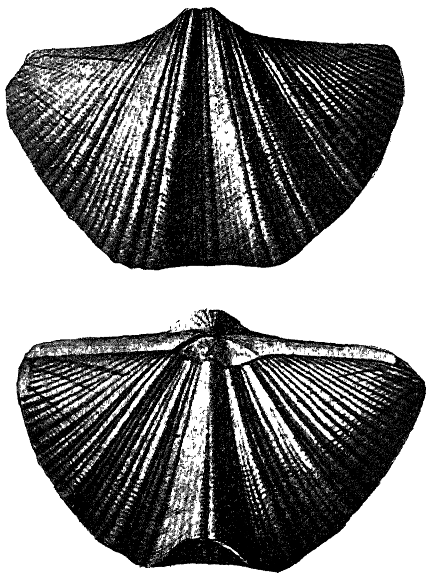


FIG. 83.—*Spirifier cameratus*.
Ventral and dorsal views.

are usually found at great depth in the seas. (E) Cephalopoda. One order of this branch, the Tetrabranchiata (four gills) have an external shell of many chambers but only the last one being inhabited; the second order is the Dibranchiata (two gills) have

an internal shell or it may be entirely wanting. The head bearing eight or ten arms encircling the mouth. Cephalopods were the strongest competitors of the Vertebrates, and were known in the Cambrian with maximum development in the Silurian,

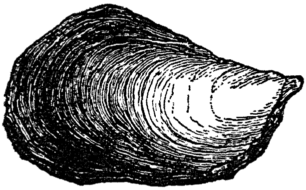


FIG. 84.—*Ostrea Idriænsis.* (After Gabb.)

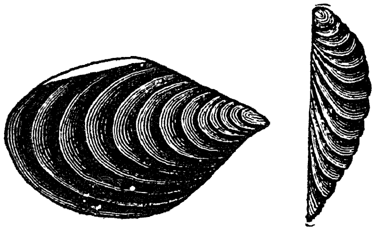


FIG. 85.—*Inoceramus dimidius.* (After Meek.)

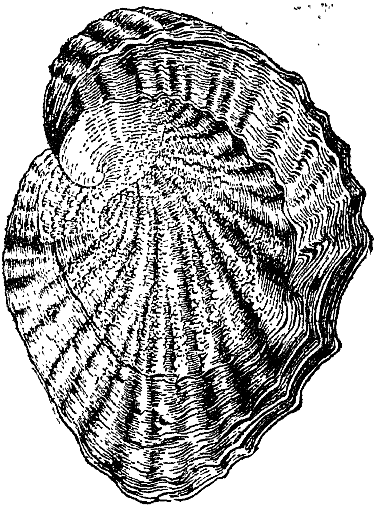


FIG. 86.—*Exogyra Texana.* (After White.)

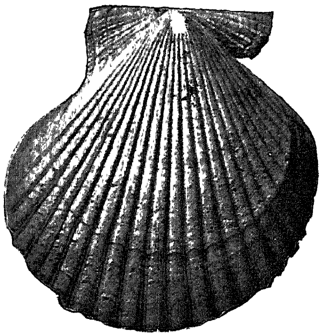


FIG. 87.—*Pecten (Plagioctenium) deserti Conrad.* (U. S. G. S. Bul. 398.)

declining towards the Triassic. The Ammonites of the order Tetrabranchiata are usually coiled in closely, in a flat spiral and are important "index-fossils" of the Mesozoic. The Belemnites of the order Dibranchiata are also important as index of the Jurassic and Cretaceous.

PHYLUM XI. ARTHROPODA

Transversely segmented animals with a hard shell of external covering (chitin) and the various subdivisions include the (A) Crustacea, such as cray-fish, which are aquatic, carnivorous animals. The Trilobites are a subclass of the Crustacea and

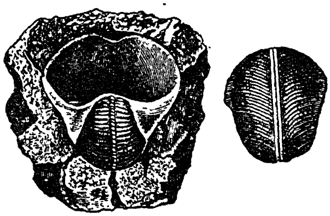


FIG. 88.—*Bellerophon Newberryi.* (After Meek.)

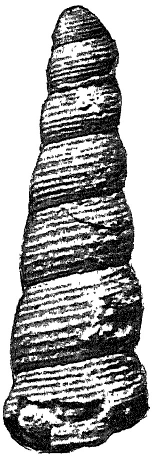


FIG. 89.—*Turritella uvasana* Conrad. (U. S. G. S. Bul. 398.)

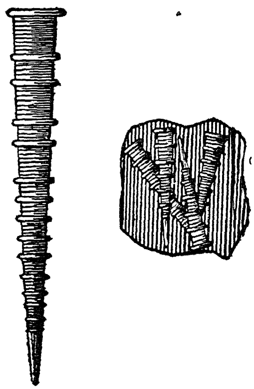


FIG. 90.—*Tentaculites.*

other similar sub-divisions of it are the Phyllopoda which are small, elongate, fresh-water animals. The Ostracoda are minute brackish, fresh-water, as well as marine creeping animals. The Copepoda are unknown as fossils. Cirripedia or Barnacles are degenerate form of Arthropoda, either fixed or parasitic marine forms. Malacostraca consist of thorax divided into eight, and the abdomen into seven segments. It will be noticeable that

the Trilobites are strictly Paleozoic forms, becoming extinct at the end of the Permian.

Subdivision (B) Onychophora have no fossil representatives. (C) Myriopoda have a worm-like body with many similar segments bearing legs (Centipedes). (D) Arachnida, of which

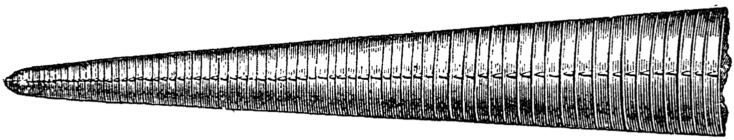


FIG. 91.—*Orthoceras Duseri.* (After Hall.)

the Spider is a typical example, have several orders of which Eurypterida is the most important. (E) Insecta. Insects, bugs, flies, etc., are classified under this heading.

PHYLUM XII. CHORDATA

Life has reached the highest form in this phylum, the main advance being in the development of a second body-cavity in which the nervous system is arranged, known as the spinal cord.

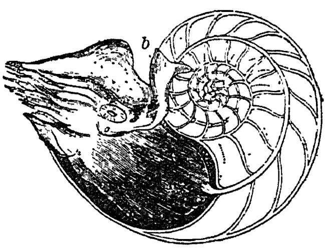


FIG. 92.—Pearly Nautilus (*Nautilus pompilius.*)

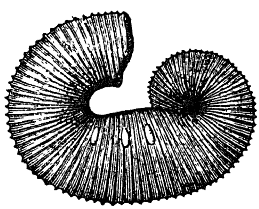


FIG. 93.—*Scaphites aequalis.* (After Pictet.)

The members of this phylum are known as Vertebrates to distinguish from the members of other phyla, which are referred to as Invertebrates.

The first sub-phylum Adelochorda have no fossil representatives. Urochorda are a degenerate form of Chordata, also unknown in the fossil state. The third sub-phylum is the main

group and are divided into several sub-divisions, the two main subdivisions being first, the Acrania, or animals whose true head is absent, brains but slightly developed and no heart present. No fossil remains of this division are known. The second or Craniata is composed of animals having a true head (skull)

FIG. 94.—*Baculites chicoensis Trask.* (Gabb, U. S. G. S. Bul. 398.)

highly developed brains, pair of complex eyes and heart and blood with red corpuscles.

The Craniata are the most important of the Vertebrates and its subdivisions are as follows:

(*A*) Cyclostomata is composed of degenerate eel-like fishes.

(*B*) Ostracodermi, are animals having a large shield or armor composed of several pieces completely enclosing the head.

(*C*) Pisces or fishes.

(*D*) Amphibia. They differ from fishes in having paired

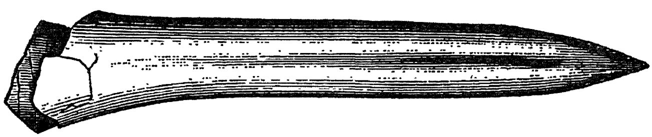


FIG. 95.—*Belemnites impressus.* (After Gabb.)

five-toed limbs instead of fins; scaly or bony covering. The order Stegocephalia are extinct tailed amphibia often of great size, living mostly in fresh water and some may have been terrestial. Urodela fossil remains are rare; they include the lizards. Anura are the frogs and toads. The Gymnophiona are snake-like without limbs; fossils are rare.

(*E*) Reptilia are cold-blooded vertebrates with two pairs of limbs with five toes; also having a horny or scaly skeleton. Some large specimens of this class are extinct and among the

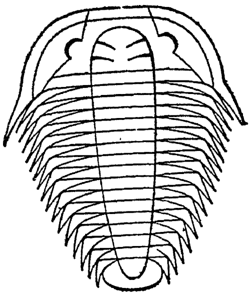


FIG. 96.—*Olenellus.*

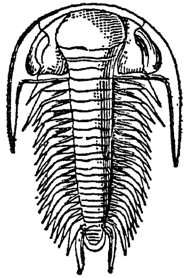


FIG. 97.—*Paradoxides.*

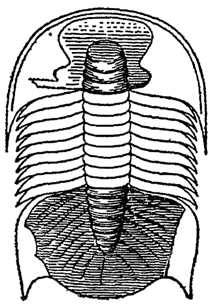


FIG. 98.—*Dikellocephalus.*

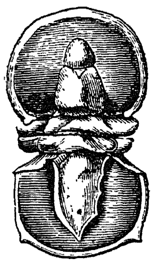


FIG. 99.—*Agnostus interstrictus.* (Le Conte.)

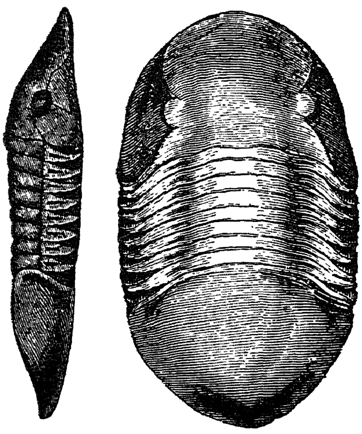


FIG. 100.—*Asaphus* (*Isotelus*) *gigas.* (After Hall.)
Also side view.

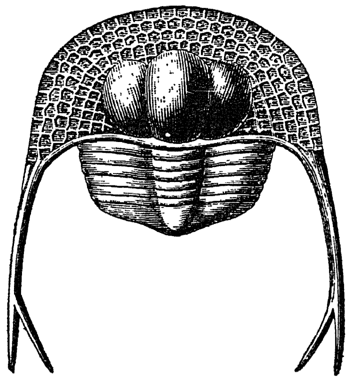


FIG. 101.—*Trinucleus Pongerardi.* (Le Conte.)

aquatic forms *Ichthyosaurs* are well-known examples. Of the land reptiles Dinosaurs (Triassic to Cretaceous) were a familiar type. The Pterosauria (Flying reptiles) appeared in the Jurassic and became extinct in the Cretaceous, *Pterodactylus* well-known fossil representative of this group. The crocodila reptiles are at present represented by the crocodiles and alligators, there are, however, several other extinct members of this branch. The order Chelonia includes reptiles having a horny or hard bony

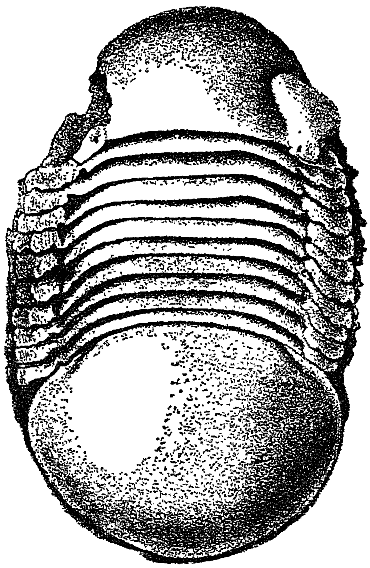


FIG. 102.—*Illaenus insignis*. (Newberry.)

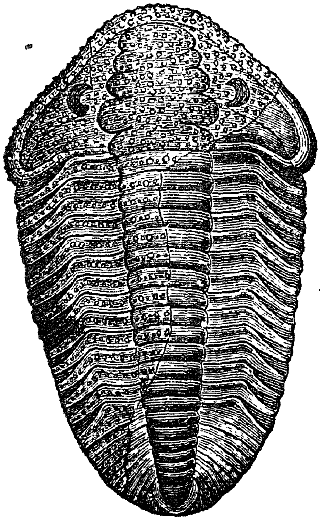
covering completely enveloping the body as in turtles. The order Squamata includes reptiles with an external protection of horny scales, and snakes are the most common example of this order.

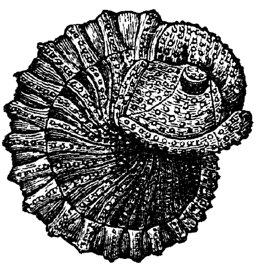
(*F*) Aves (Birds). Although Mesozoic birds had functional teeth, since the Tertiary no teeth are present. The oldest known bird is *Archeopteryx* of the upper Jurassic. The remains of birds are rarely found as fossils and of *Archeopteryx* only very few good specimens have been found.

(*G*) Mammalia (Mammals). These are air-breathing, warm-

blooded vertebrates usually with an external covering of hair. For general discussion they are divided as follows:

(*a*). Monotremata, of which only two remaining members





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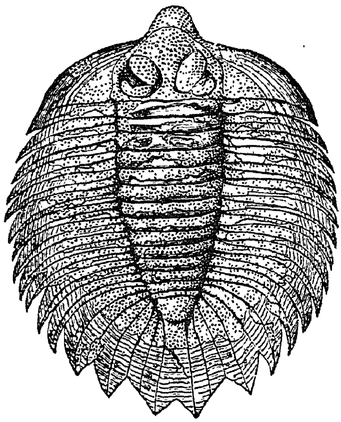


FIG. 104.—*Lichas Boltoni.* (After Hall.)

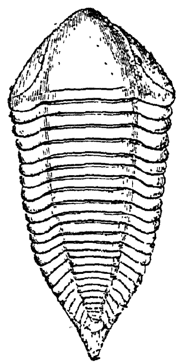


FIG. 103.—*Calymene Blumenbachii.* (Le Conte.)
(*a*) Same folded.

FIG. 105.—*Homalonotus delphinocephalus* Green. (After Newberry.)

are known, which are Ornithorhynchus (Duck Bill) and Echidna (Spiny Anteater). The young are produced as eggs and are carried in a ventral pouch, where they are hatched and nourished.

(*b*). Marsupialia produce their young alive, but are carried

in a pouch until they are able to take care of themselves; examples are the opossum and kangaroos.

(*c*). Insectivora are insect or worm eaters.

(*d*). Chiroptera have the fore limbs modified to form wings.

(*e*). Carnivora are flesh eating mammals with teeth having sharp cutting edges.

(*f*). Rodentia are fur covered, plant-eating animals.

(*g*). Edentata are degenerate forms with imperfect teeth.

(*h*). Ungulata or hoofed mammals, with none or small canine teeth, with large premolars and molars, flat footed animals, such as elephants and similar extinct mammals, as well as cattle, sheep, etc.

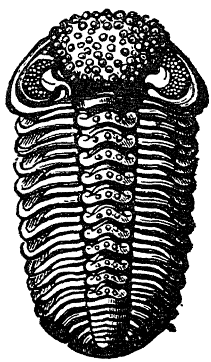


FIG. 106.—*Phacops.* (Le Conte.)

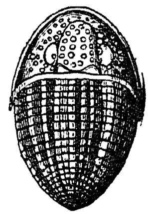


FIG. 107.—*Phillipsia Lodiensis.* (After Meek.)

(*i*). Sirena or sea cows (dugong).

(*j*). Cetacea are the whales.

(*k*). Primates, are walking mammals, with thumb and digits having flat nails, eye surrounded with bony ring. Lemuroidea are the lemurs, which are the only living survivals or a group of extinct similar mammals. Anthropoidea, which have several distinct classifications amongst which are the apes, monkeys as well as similar extinct forms. The final classification being the various extinct as well as living family of Hominidæ, or man, with modern man (Homo sapiens) at the top of the scale.

The length at which this subject is treated here does not permit a thorough understanding of paleontology and is simply

a short résumé of the various facts as treated in volumes prepared for the study of paleontology. The facts given are in part from Shimer's "Introduction to the Study of Fossils," in which these principles are taken up in greater detail. The list of fossils

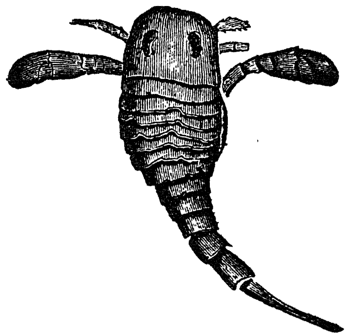


FIG. 108.—*Eurypterus remipes.* (After H. Woodward.)

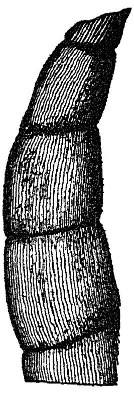


FIG. 109.—*Calamites.*

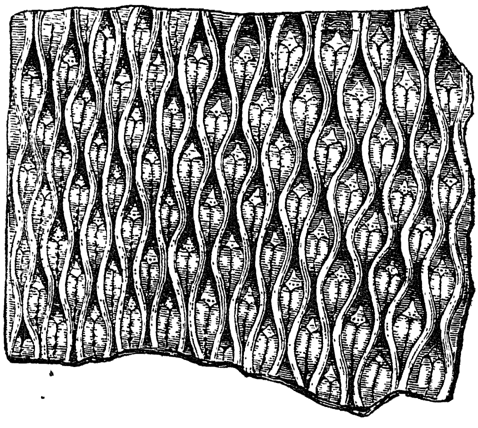


FIG. 110.—*Lepidodendron modulatum.* (After Lesquereux.)

is by no means a complete one, but merely a list of some of the best-known representatives. The geologist should be equipped with a reference volume by means of which he may identify any fossils unknown to him. For this purpose Grabau & Shimer's "Index Fossils" will be of great value.

CHAPTER XI

SCOUTING

Oil and gas companies operating in any territory are kept informed of the field developments by their scouting department. It is the duty of this department to keep in touch with the field operations of other companies from day to day and report same so that the maps may be kept up to date and the information properly filed.

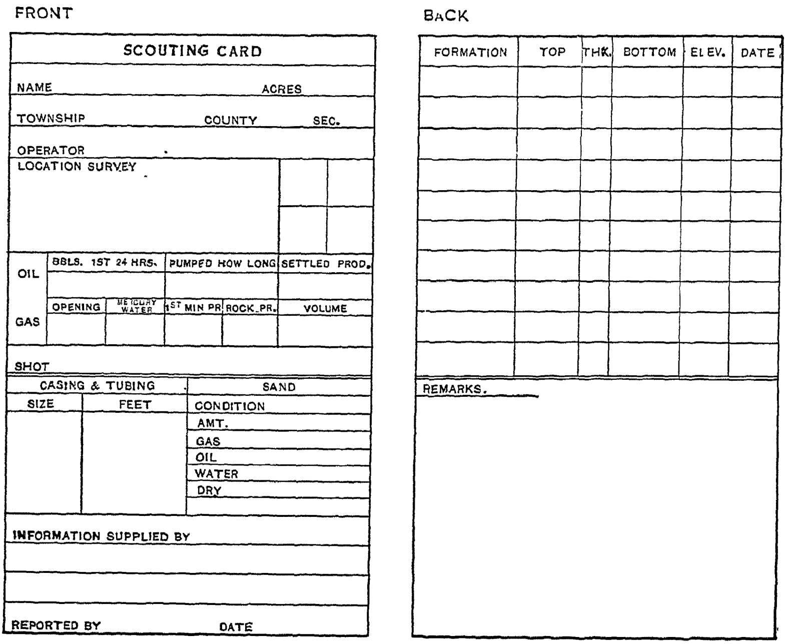
Scouting may be divided into two classes, the first comprised of territories previously drilled or abandoned, and secondly, the scouting of territory where development work is being carried on. In both cases it is carried on in conjunction with the geological work.

When an attempt is made to operate in a field that has several unsuccessful or small wells, or in a territory that is an old one but new to the producer, a scout is assigned to gather the information on that field. Equipped with the necessary maps the first step is to find all drilling, pumping and abandoned wells as well as dry holes and locate them properly on the farm map.

The various facts about the wells are to be ascertained and the following points should be investigated: The name of the parties operating as well, as the name of the contractor is an important point, as these people may be interviewed and give valuable information and data on the well and perhaps furnish a record of the well. The time the well was drilled and the prevailing price of oil at the time is of value, as it may be found that owing to a possible low price of oil the wells were not at the time commercial propositions but at a higher price for the oil the same wells might have been of value.

Information regarding the following points may lead to a clue as to the wells' probable value: If the well was pumped,

how long and why was it abandoned, was the well shot and with how many quarts of nitro-glycerin? The size of the shot may indicate the thickness of the sand, as it is customary to place the shell containing the glycerin right against the sand, and the length of the shell will be determined by the thickness of the sand. In this connection the size of the hole at the sand must be known. A shooting table will show the length in feet a certain


FRONT

SCOUTING CARD

NAME ACRES

TOWNSHIP COUNTY SEC.

OPERATOR

LOCATION SURVEY

OIL	BBLS. 1ST 24 HRS.		PUMPED HOW LONG		SETTLED PROD.
GAS	OPENING	MERCURY WATER	1ST MIN PR	ROCK PR.	VOLUME

SHOT

CASING & TUBING		SAND
SIZE	FEET	CONDITION
		AMT.
		GAS
		OIL
		WATER
		DRY

INFORMATION SUPPLIED BY

REPORTED BY DATE

BACK

FORMATION	TOP	THK.	BOTTOM	ELEV.	DATE

REMARKS.

Practical Form 1, Scouting Card.

number of quarts of nitro-glycerin will occupy in a shell of a certain diameter.

If a well was shot it may indicate that the drillers thought well enough of the showing of oil or gas in the sand to shoot it. Whether the sand contained water or not should also be determined.

If the operators or drillers cannot be located or they would not give out the required data, the land owners in the vicinity

of the wells may be able to give some information. Such information must be carefully analyzed, as it may prove to be a biased opinion. Land owners are as a rule optimistic about the oil and gas possibilities in their neighborhood and thus may be giving only their point of view. Small and commercially unimportant showings may look large to the non-oil man. In case of gas propositions the general information obtained from such sources gives the pressure of the gas and seldom its volume. A clear distinction must be had between gas pressure and volume.

Large gas wells are seldom shot, so if a well was torpedoed to increase the volume of gas, its original size must have been small. It may be learned whether when drilling into the sand the gas volume was large enough to prevent drilling the hole wet, and in the case of fair-sized gas wells, water cannot be poured down the hole to assist in the drilling, but it must be lowered in the bailer or no water used at all.

The second class of scouting may be referred to as routine work. In the Western States this department is on a comparatively high scale. The entire territory in which the operators are interested is divided into several districts with a scout in charge of each. It is his duty to keep the company informed as to the new locations that are being made by others, the rigs built, drilling wells, the depth at which they are drilling, the time the well is expected to be completed. The scout should be present when the wells are drilled into the sand or if his duties require his presence elsewhere he is to notify his firm so that someone else may be sent out to watch the well. The scout must also be on the lookout for any leasing that may be going on, also to keep in touch with the production of the various wells or leases. Scouting reports are generally made each week.

From the foregoing it will be noted that a scout must be a good oil man himself, so that he may be able to pass judgment on his findings, must be familiar with the sands and make a good interpretation of the showings of oil or gas in them and also be able to understand and verify any statements that are heard.

Access should be had to gauging instruments, as the oppor-

tunity to gauge a tank or determine the size of a gas well may present itself at any time, therefore he must become familiar with the methods of gauging.

The scout must be familiar with maps and have a general idea of surveying and needless to say understanding of geology is important.

CHAPTER XII

METHODS OF LOCATING WELLS

AFTER the examination of the geological conditions in the field, coupled with all available data, we may, by a systematic study, make the location for a prospect or an off-set well intelligently. In a "wild-cat" territory the initial test should be made on the highest point of the best structure found, preferably a dome or level top anticline. The horizon sought for is determined by the examination of the columnar section made from observing the various outcrops and studying their suitability as oil and gas reservoirs. Alternating shales and sandstones are considered as an ideal section, especially if the shales predominate. Any information as to the convergence of the strata should be allowed for, as well as for the shifting of the anticlinal axis of the producing horizon to one side of the axis of the surface structure, caused by the asymmetry of the anticline. It will be noticed that where the angles of dip on each side of the axis are different, there will be a shifting of the axis of all underlying strata and in the direction of the lesser dip. (Fig. 16.) The distance of the shift or heave may be determined if the approximate depth of the sand is known by plotting the structure to scale, both the surface and the sub-surface structures, and the distance may thus be scaled off. Otherwise trigonometric factors have to be employed.

If the initial well proves to be a successful oil well, the next location, to be placed in a favorable direction, should be along the strike of the rocks, so that the sand may be found at a correspondingly same level as in the original well. Should the initial well prove to be a gas well, and the object of the search being oil, the location should be down the dip from the gas well.

The general trend of an oil pool is to be expected in the direction of the strike of the rocks, which will be changed only by lensing, and under such conditions the direction may be varied; such pools are known as streak pools. The direction of the major or long axes of other pools in the vicinity may throw some light on the possible trend, as the conditions of neighboring pools may be similar. It is advisable to know whether a pool is found in a well known sand, or in a patch of sand that has been struck unexpectedly. Such sands are known as stray sands, and may prove to be of small extent, and may give rise to narrow pools, which are generally referred to as "sucker-rod" pools. Although this cannot be laid down as an iron clad rule, still stray sands need careful watching and their characteristics noted.

In a new territory where no chance is offered for the study of neighboring pools, the probable direction of the pools may be in the direction parallel to the inferred shore-line, at the time of the deposition of the "sand"; as the coarser particles were deposited near and parallel to the shore-line. Only by a geological study can the direction of such a shore line be determined; and its direction may be expected at right angles to the deepest water, which would be indicated by the thickening of the strata, changing from coarser to finer sediments and to limestones, which will be increasing in purity towards deeper water.*

The general persistence and pressure after a field has been developed for some length of time is claimed to indicate the presence of oil or gas in near-by untested territory. This condition is indicated by the oil man's statement "that the well is being fed from some place the way the pressure stays up."

Analysis of the gases as well as the water encountered in drilling are of importance. Dry gas generally indicates that it is far removed from the oil, or in some cases (in shallow sands) that no oil is present in the reservoir. The presence of gas without oil in a thick water-bearing formation greatly lessens the chances of oil being found in that formation; this will hold good if the structure is lower than the water table in that formation in a certain synclinal basin. Oil may be expected at or

* Johnson and Huntley, "Principles of Oil and Gas Production."

above the water table, along the homoclinal dip. The big pools of Corning, Ohio, and Scio, Ohio, are so situated.

The chemical analysis of water found in drilling will enable one to determine the presence of oil or dissolved gas in it, and therefore the presence of either one may be expected further up the dip if the analysis shows their traces. If a well is drilled in an old abandoned territory and water found, the water may be from the sand itself or leaked in from other improperly plugged wells, such a possibility may be determined by a chemical analysis of the water found in the sand and the water that has been cased off above the sand at higher levels. This may also be used in connection with pumping wells, to determine whether the water that is pumped with the oil is from the oil sand or from above it.

Water conditions may determine the extent of deeper pools, and if it is borne in mind that of two sands of equal porosity and equal thickness, the upper or younger one will be more thoroughly saturated with water than the lower or older stratum, therefore it may be expected that the edge of the underlying pool will not be directly under the upper one, but will extend further down the dip.

Interesting and valuable information is pointed out by Carl H. Beal in Bulletin 658 of the United States Geological Survey, wherein he states: "The evidence indicates that in general the oil and gas areas in an elongated dome, where folding is simple, extend farther down on the long axis of the anticline or dome than on the steeper sides. In other words, the area that contains water only, occurs at a higher structural position on the steeper sides of an elongated dome than it does on its plunging axis." (Fig. 111.)

Whether two pools in the same sand may or may not be connected some information may be had by the comparison of the pressure and gravity of the oil. If it is found that the properties of the oil and gas are similar it may be expected that the two pools may be connected. Care must be taken that the samples of the oils are a true representation of the field, as it is possible that the gravity of the oil in a pool may have undergone some change; wells have been known to produce oils of different

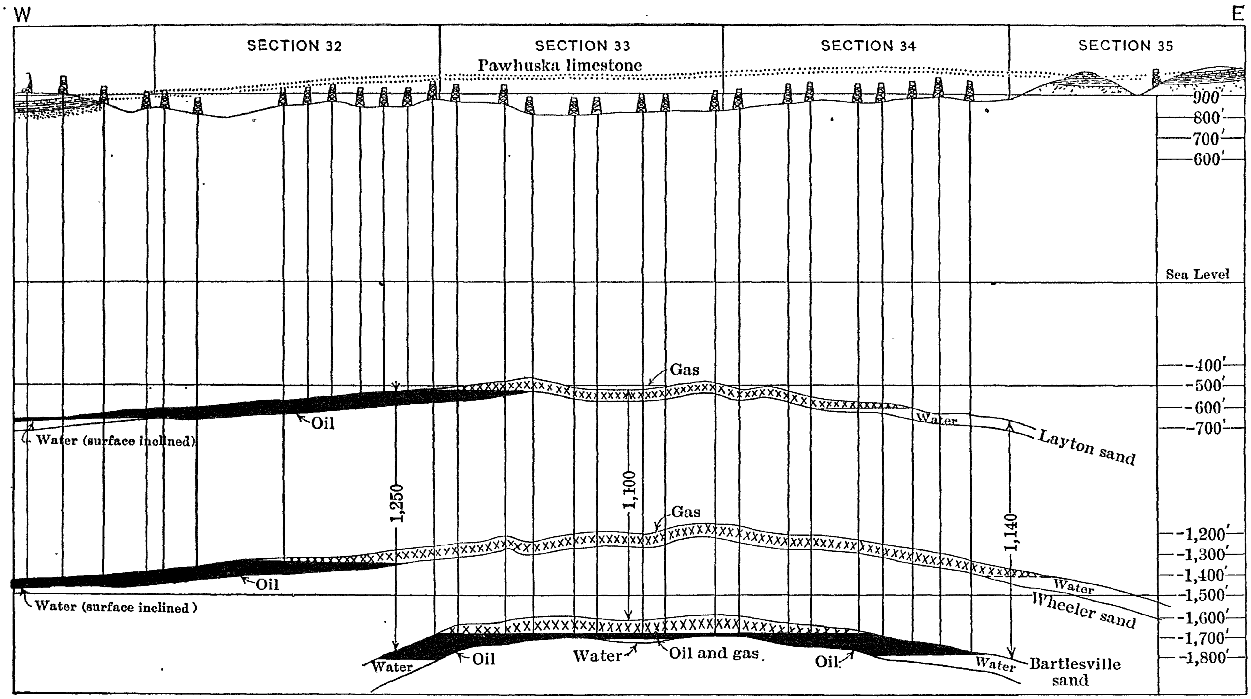


FIG. 111.—Sketch section along south line of T. 18 N., R. 7 E., through the Drumright dome, showing the stratigraphic relations of the Pawhuska limestone and the Layton, Wheeler, and Bartlesville sands, the increase in the Layton-Bartlesville interval, and the inclination of the water surfaces. (Bulletin 658, U. S. G. S.)

gravities at various times, and the rock pressure in one pool might have undergone a greater decline than the others. Artificial methods of production, such as the use of compressed air, may lower the gravity of the oil, and lessen its gasoline value, and therefore will lower the value of the casinghead gas for such a purpose. It is necessary, therefore, that when a comparison is made between two pools, they should be studied under similar conditions.

David White's studies have shown a valuable relation that exists between the overlying coals and their extent of alteration, and oil and gas deposits, and he states that "In regions where the progressive devolatilization of the organic deposits in any formation has passed a certain point, marked in most provinces by 65 to 70 per cent of fixed carbon (pure coal basis) in the associated or overlying coals, commercial oil pools are not present in that formation nor in any other formation normally underlying it, though commercial gas pools may occur." Further on he states: "The lowest rank oils of each type are found in regions and formations in which carbonaceous deposits are least altered, . . . the highest rank oils being, on the whole, found in regions where the carbonaceous deposits . . . have been brought to correspondingly higher ranks."

Spacing of Wells. The distance between wells in most cases is determined by the various usages or customs in the field. In a consolidated sandstone or magnesian limestone field, closely spaced wells cannot be expected to bring good results, and for that reason all town-lot developments are to be discouraged, as it may safely be stated, that out of ten producers, it is unlikely that more than one will make a financial success of his holdings, and past history will bear out this statement in all instances. Wells may come in with a large initial or flush production, but with many wells draining a small area, the number of barrels of oil per well must necessarily be small. Although such developments may be a Mecca for the drilling contractors, they are far from being good prospects for the oil man. The rule in all such cases should always be: KEEP AWAY FROM TOWN-LOT EXCITEMENTS.

In general practice it is customary to off-set wells, that is, the opposing producers either by mutual agreement or through custom, will stay equal distances away from each other's property line. If a well is being drilled 300 feet from the property line, the owner of the adjoining lease will off-set this well if it proves to be a good producer, and stay 300 feet from the line, making the entire distance between the two wells 600 feet. Under ordinary conditions the following rule of thumb may be applied to spacing of wells: in a shallow field where the depth of wells does not exceed 500 feet, the wells should not be less than 400 feet apart, and about 150 or 200 feet from the property lines. Where the wells are deeper they should be at least 600 feet apart, 300 feet away from the property lines. This rule may be applied to oil wells, while for gas wells the distances should be greater, and it is good practice to locate one gas well to forty acres, in a gas belt where the wells are 2000 feet or deeper.

Although the above rule may be employed, it is by no means the best method. No two territories are alike and therefore a rule that will hold good for one field may be detrimental to another. The methods of spacing wells depend upon the porosity of the sand, the dip of the formation and the water in the sand. Consideration should also be given to the physical properties of the oil and the pressure of the gas.

Where the effective porosity of a sand is large, as in the case of the Texas salt domes, the Mexican water-channeled limestones, the California and Russian unconsolidated formations, the wells are generally located very close together, the large amount of oil produced puts such wells on a paying basis, but from an economic standpoint such close spacing is unnecessary; one well will drain a much larger area under these conditions than it would in a relatively less porous sand.

If the producing sand body has a pronounced dip, the wells should be closer together along the line of strike than along the dip. The water level must be watched, and in the case of large holdings it may become possible that the encroachment of water up the dip may be retarded by a vigorous pumping of the

wells down the dip to check the upward movement of the water.

In a newly discovered pool the pressure of the gas is much larger and therefore, the original wells will produce a greater amount of oil during the initial stages than the wells that are drilled when the pool has been drained to a large extent.

There are various methods advocated whereby a certain number of wells may be off-set by a less number of wells, at the expense of some lost territory, but at a gain in the number of wells drilled. A method of computing the lost areas as stated by Johnson and Huntley, in their "Principles of Oil and Gas Production," is as follows: Draw lines on the map midway between each line well and its two opposing line wells, if one is not exactly opposite. This is done by drawing circles with each

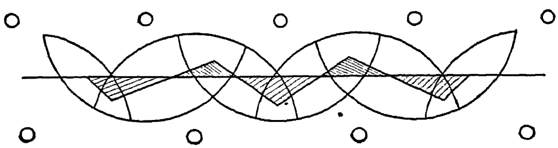


FIG. 112.—Graphic Method of calculating loss of oil where offsetting with a fewer number of wells. (Johnson and Huntley.)

well in question as a center and joining the points of intersection with a line. These lines make triangles with the lease boundary showing areas lost or gained. (Fig. 112.)

The area of the lost territory thus outlined must now be computed as well as any territory which may be gained from the neighbor. This may be done by making this construction on cross-section paper, counting the number of squares or fraction of squares included in the area. A more exact method is to compute the area of the triangle by the well-known formula of the base times one-half the altitude. In the event that the area is polygonal instead of triangular, it is divided into triangles the area of each computed and added together.

Discoveries of new pools generally create a great excitement and an inrush of oil men, and during such times it is advisable

that the geologist should not be misled by the various stories that are being told, but to go out in the field and obtain all the information that is reliable and base his deductions on unbiased data obtained from the evidence shown by the geological conditions coupled with any other information available.

CHAPTER XIII

DRILLING METHODS

THAT oil or gas may be obtained it is necessary that a hole be bored or drilled through the formations in order that the producing horizon may be tapped. The most common methods employed for drilling are the Rotary and Cable systems. The choice depends upon the character of the formations. Thus, in the majority of cases the strata are quite solid, so that the walls of the holes drilled are quite firm and will not cave immediately; in such cases the standard cable or percussion system may be used. On the other hand, where the drilling is through soft formations that easily cave, the rotary method is the one adapted for the work. In some cases it is of advantage to combine the two methods so that a change from one to the other may be made whenever necessary.

The rotary system consists in turning a column of pipe, the lower end of which is fitted with the cutting tool, which when rotated will penetrate through the formations, and as the hole is deepened the tools are lowered by the addition of more pipe, which also acts as a preventive (or casing) against a caving hole. Water is forced through the pipe, which is under pressure, temporarily holding the wall, also when it returns to the surface it will bring the cuttings with it. The returning water is examined and thus the various formations passed through may be recognized.

The standard cable system differs in that the hole is drilled by the raising and dropping of a heavy steel tool, which is a "bit," and by means of additional weight given it by the stem, sinker bar, jars and rope socket, will cut through the formations. The tool is lifted by means of a walking beam which is attached to the wrist pin of the main driving shaft crank. The tool is

Practical Form No. 2

SIMPLE FORM OF DRILLING CONTRACT

Date........................

We,...Ohio, being familiar with the location and surroundings of Well No............. Serial No.............located on..............................farm Situated in.........................Township,...................... County, Ohio, do hereby agree to drill a well for The .... Company at such location to and through the Clinton Sand or to Medina Sand, if requested to do so, or to any point above at which they may order drilling stopped, clean well out to bottom after shot and tube it, for the consideration of $............per foot to be paid us by The.............. Company, the said The.......................Company to furnish rig, pipe, casing and tubing to drill said well. The Contractors to furnish fuel, water and all other material necessary to drill well.

We have examined the drilling rig as built, and accept the same as safe and satisfactory for such drilling purposes, and we hereby assume all risks of accidents to ourselves and employees from breakage or otherwise during said work, above work to be done in a diligent and workmanlike manner.

It is further agreed that should it require more than two days to clean out said well after shooting, that for any additional cleaning out (after said two days) The.......................Company shall pav $25.00 per day for 12-hour days. The.......................Company to furnish fuel for cleaning out purposes only.

In case said well should not pay to tube the said Contractors are to plug and pull all material out of said well that can be reasonably pulled at their own expense.

.......................Company.

Witness.......................Signed.............................

Witness.......................   ....

Witness.......................   ....

Practical Form No. 3

DRILLING CONTRACT

....

THIS AGREEMENT made and entered into this.................. day of............................19...., by and between the following named parties:...

....

a corporation organized and existing under the laws of the State of........ and having its principal place of business at............................ and.. a corporation, company or individual, organized and existing under the laws of the State of...................., and having its principal place of business at.........................., hereinafter called the Contractor:

WITNESSETH

That the parties hereto, for and in consideration of their mutual covenants hereby agree as follows:

The Contractor agrees to drill a well for the .... in accordance with the specifications hereinafter contained. Well to be known as...
Lease number..........Well number..........Serial number..........
on that certain piece of land known and described as follows:
Land Owner, Lot or Farm name....................................
situated in................Township,.........Section,........County,
State of...
and the........................Company agrees to pay the Contractor for said work, the amount, in accordance with the terms, hereinafter prescribed.

DRILLING CONDITIONS

The Contractor shall commence the drilling of said well within ....days after the execution of this agreement and shall prosecute the work of drilling said well continuously thereafter until said well is fully completed to the entire satisfaction of the.................... Company.

The Contractor shall set a string of..........inch casing in said well from the surface to a depth to be indicated by the.................. Company from...
The Contractor shall also set a string of..........inch casing in said

well from the surface to a depth to be indicated by the.................. Company

The CONTRACTOR shall also set a string of............inch casing in said well from the surface to a depth to be indicated by the.............. ....Company.

The CONTRACTOR shall set all the above named casings and any other casing, in accordance with and under instructions of the............ ....Company and after the setting of each string of casing the well shall be bailed sufficiently to ascertain if the water has been shut off, and the well shall then be allowed to stand for................hours to test the same. If the water has not been shut off after the setting of any string of casing, the CONTRACTOR will then furnish...................days' free labor, under the instructions of the.............................. Company, in a further endeavor to shut off the water.

GUARANTEES

The CONTRACTOR agrees that all work shall be done in a good and workmanlike manner; that the casing when set shall be open to its full diameter and to its full length so as to permit the passage throughout its entire length, of the next smaller size casing, free and unobstructed.

In the event of the inability of the CONTRACTOR to complete said well in accordance with the terms and conditions hereof, for any cause, the CONTRACTOR shall immediately commence the drilling of a new well at a point to be indicated by the.................................... on the above described property, which new well shall be completed in accordance with all the terms and conditions hereof, provided however, that the CONTRACTOR shall carry such new well to the depth at which the first well is lost, free of any additional cost to the...................

TOOLS, MATERIALS AND SUPPLIES

The........................Co. shall furnish a Standard derrick complete and the same shall be erected at a certain point on the above described land.

The........................ Co. shall also furnish all pipe, casing and tubing necessary to drill said well................................ ....

The CONTRACTOR shall furnish all labor, all machinery and drilling tools, all drilling lines, all casing lines and blocks, all working and fishing tools and any and all other materials, supplies and tools not specifically provided to be furnished by the..................................Co.

All material and apparatus which it is specifically provided to be furnished by the......................Co., shall be in good condition and

shall be maintained in good condition by and at the expense of the CONTRACTOR and shall be returned to the............................Co., at the expiration of this contract in good condition and repair, subject to the ordinary wear and tear.

MEASUREMENTS AND RECORDS

The CONTRACTOR shall keep a complete and accurate log of the well, which shall at all times be open to the inspection of the........................Co., and its duly authorized representatives. The............................Co., and its duly authorized representatives may at any and all times inspect the work and conditions and take such measurements as they shall desire.

LIENS

The CONTRACTOR agrees to save and hold harmless the..........................Co., and the land hereinabove described from any and all claims or liens of labor or supplymen or supply stores arising out of the drilling of said well and against the claims of CONTRACTOR'S employees for injuries received in the course of said work upon said land from any and all causes whatsoever.

The CONTRACTOR agrees to examine the drilling derrick as built and any and all other apparatus which may be furnished by the.......................Co., and accept the same as safe and satisfactory for such drilling purposes and agrees to assume all risks of accidents to themselves and employees from breakage or any and all other causes.

PAYMENTS

The............................Co., agrees to pay to the CONTRACTOR the sum of $...............per linear foot for each foot of hole drilled and cased to the entire satisfaction of the...............................Co.,...

....

....

BREACH

Upon the failure of either party to fully keep and perform each and all of the terms of this agreement, then the agreement may at once be terminated at the option of the party not in default.

If the defaulting party be the........................Co., then all work completed shall be forthwith paid for to the CONTRACTOR at the full contract price per linear foot.

If the defaulting party be the CONTRACTOR, then all rights to moneys due under this contract shall be forfeited.

Any breach of this contract by the........................Co., requiring the CONTRACTOR to shut down for more than .... consecutive hours shall entitle the CONTRACTOR to $.................. per day during the time actually shut down in excess of.................. consecutive hours.

Delays occasioned by strikes or the elements or any and all other causes beyond the control of either party shall not be deemed a breach of this contract.

....

ARBITRATION

Any and all disputes or controversy arising out of this agreement shall be referred to three arbitrators, one to be selected by each of the parties hereto and the two so selected to appoint a third. A decision by the majority of such arbitrators shall be binding upon both parties.

Time is the essence of this agreement and this agreement runs in favor of and is binding upon the successors and assigns of each of the parties hereto.

IN WITNESS WHEREOF, the parties hereto have caused their respective names and seals to be hereunto affixed by their officers first thereunto duly authorized by resolution of their respective Companies or Boards of Directors, the day and year first hereinabove written.

The......................Company

Witness...................... By......................

Witness......................

Witness......................

The....................Contractor

Witness...................... By......................

Witness......................

Witness......................

attached to the drilling rope which in turn is attached to the walking beam by means of the temper screw. This operation can be carried out only after the hole is deep enough to permit the string of tools to be lowered into it so that it may be attached to the walking beam by means of the temper screw. Until the

FIG. 113.—Standard Drilling Derrick.

required depth is obtained, spudding is resorted to, which consists in the lifting and dropping of the tools by means of a jerk-line attached to the wrist pin, and the other end to the drilling rope by means of a spudding shoe which works freely along the line. The jerking motion imparted to the rope lifts the tools in the derrick and as the hole is being deepened more rope is

let out. The removal of the cuttings is accomplished by lowering a bailer with a dart valve at the bottom and the cuttings are brought up. (Fig. 113.)

Both systems of drilling require a tall derrick for the purpose of drilling so that the tools and casing may be lifted up vertically before they can be inserted in the well. In fields where the depths are not over 2000 feet, portable drilling machines are in use, which differ from the standard derrick in being lighter and using a high mast instead of the derrick tower.

When the location in the field is made and properly surveyed, the next step is the building of the rig, which is done by contract with people whose vocation is the erecting of such structures. When the rig is up (Fig. 114) the companies' or the drilling contractors' men will string their tools and soon the well is spudded in.

The drilling is mostly done by drilling contractors who agree to drill a well to a certain depth or through a certain sand for a specified price, which varies in different localities, depending upon the accessibility of the location, the depth of the well and other conditions that will affect the drilling, the price ranges between one to seven dollars per foot. The success of the drilling contractor depends upon the smoothness with which the operation has been carried out, numerous fishing jobs will eat into his profit considerably and in case of continued misfortunes may show considerable losses.

In the standard system of drilling various size casings are used at different depths to keep the wall up and to case-off water that may be encountered during the drilling. In most cases a certain amount of surface soil is to be drilled through before the underlying rocks are reached; this surface soil may consist of gravels, which are quite thick along river bottoms and in glaciated countries. If it is but a few feet, a 12-inch hole is started, and an octagonal shaped wooden conductor or casing is inserted, but if the drift is thicker a large size casing known as the drive pipe is used. A short distance is drilled by spudding and the drive pipe allowed to lower down, and generally driven down by clamps attached to the drilling stem, and this continued until

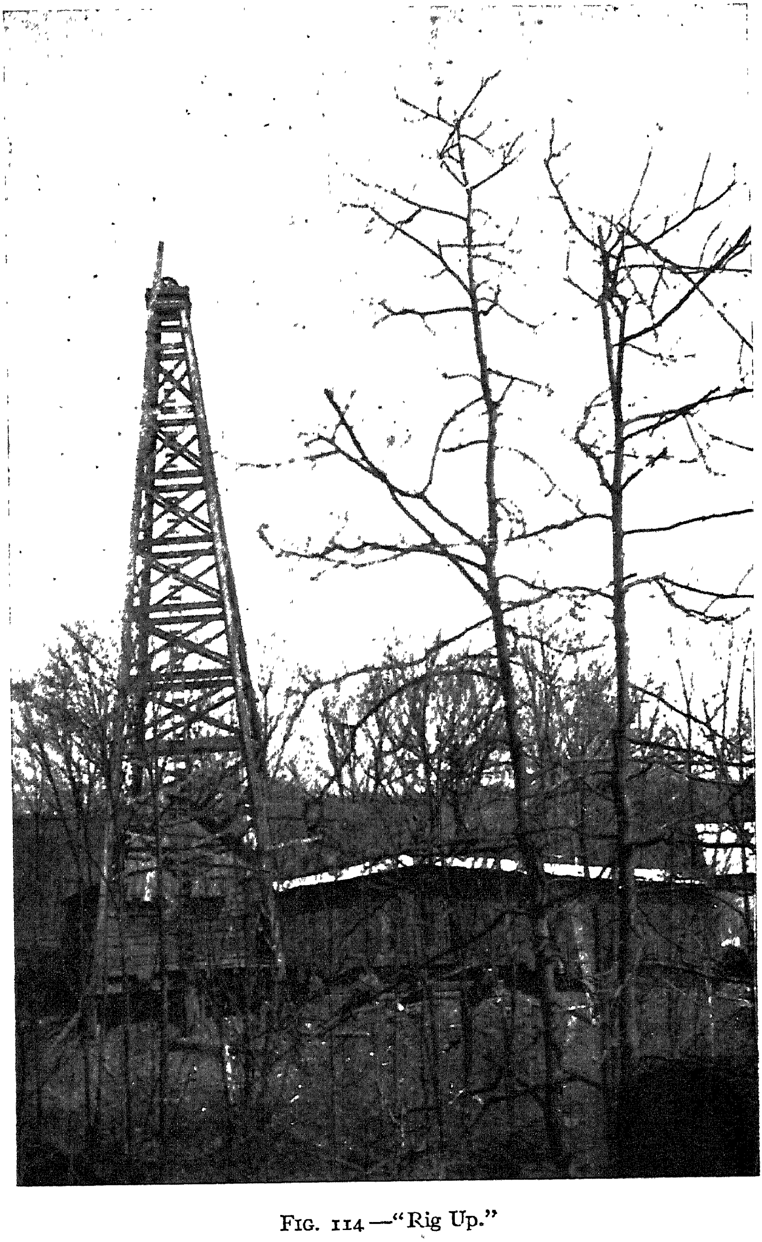


FIG. 114—"Rig Up."

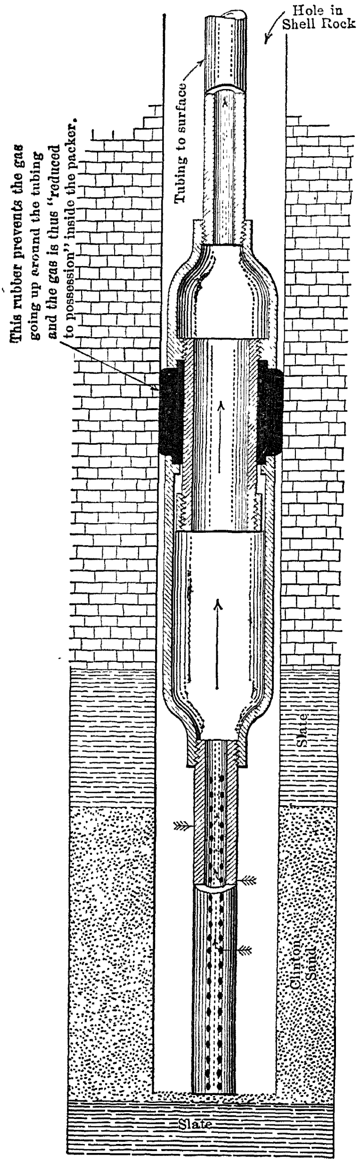


FIG. 115.—Packer at Bottom of Gas Well. (After S. S. Wyer.)

solid bottom is found. Where large boulders are encountered, care must be taken to drill through them, as driving the pipe against such boulders will cause the bottom of the casing to bend, especially if a light-weight casing is used. Such boulders may be dynamited, but if all attempts to remove them or drill through them fails, the rig will have to be moved or "skidded" and a new hole started. Such boulders may cause a crooked hole, as the tools hitting them a glancing blow may be diverted and thus the crooked hole started.

After the successful landing of the drive pipe, drilling is resumed with the next smaller sized tool and continued until for some reason or other another string of casing is to be inserted. The different points where new strings of casings are needed are well known in a developed pool, and the size of the hole with which the wells are started depends upon the number of times the hole is to be cased, as each successive casing is of a smaller diameter. Each string of casing reaches from the top of the well through the object which is to be shut off. and the bottom landed in a solid rock.

The object which is to be cased off, whether it is caving or water, must be prevented from going below the casing and thus into the hole, and for this special casing shoes are used or a "packer" placed at the bottom of the casing. The old system of packing off water consisted in placing a seed-bag, which as the name indicates is a bag filled with seeds, which will expand or swell up when in contact with water, so that if such a seed-bag is inserted between the wall of the hole and the casing below the source of the water, it will prove to be a means of shutting off the way for the water to enter the sand. Seed-bags are seldom used at the present time, and in place of them specially prepared packers are used; they come in different styles and sizes, depending on the peculiarities of the different conditions. The object of the packer is the same as that of the seed-bag and it is accomplished as follows: a hollow rubber cylinder is placed between two flanges, and the weight of the casing above will cause the rubber to bulge outward and come in contact with the wall of the hole, forming a strong seal. (Fig. 115.)

During the course of drilling, various difficulties may present themselves; it may be that the drilling cable will break, or the joined parts of the tools may become unscrewed, the stem may break, a string of casing may drop in the hole, or some other similar accident may occur; in each case a "fishing job" is on hand. By the use of various fishing tools, depending on the nature of the job, lost objects may be recovered. If not, they may be drilled past and cased off, or the rig skidded and a new hole started.

The general system of casing consists in screwing the joints of pipe together each about 20 feet long, and lowering them into the hole. There are various ways in which the joining together of the several joints may be accomplished.

Quite often it is necessary to drill a hole while it has considerable water in it, and before casing came into use all wells were drilled "wet." The process is not only slow, but dangerous, as showings of oil and gas may be overlooked, and if discovered it is hard to determine whether there is any water in the producing sand with the oil or not.

Practical Form No. 4

DRILLING INDEX CARD

Lease No.	Well No.	Serial No.	
Land Owner			
	Township		County
Sec. No.	Lot No.	District	Acres
Operating Co.			
Address			
Contracting Co.			
Address			
Price $ per Foot.	Remarks:		
Fuel Used			Price $
Commenced 19 .			
Completed 19 .	No. of days		
Drillers			
Dressers			
Remarks:			
Rig Commenced 19 .	Rig Completed 19 .		

	Locating Data
G F M P	Condition of Location Ground. F=Fair. G=Good. M=Medium. P=Poor.

Location Dated		19
Location Received		19
Location Reported		19
Meter Name	No.	
Connected		19
State		
Disconnected		19
State		
Consumed	M.Ft. $	
Meter Name	No.	
Connected		19
State		
Disconnected		19
State		
Consumed	M.Ft. $	
Report on Sands		
Total Depth	Ft. Rock Pr.	
Volume		Bbls.

																	Date
																	Operating Conditions

Practical Form No. 5

THE DRILLING COMPANY

Commencement Notice—Drilling Department

Lease No.	Name		Well No.	Serial No.
		Township		County, State of
Was Commenced			Date	19
By		Address		
Company Operating				
Rig Commenced		19.	. Rig Completed	19 .
Kind of Fuel Used		Purchased from		
Meter Name	No.	No.	State of Meter	000 Cu. Ft.
Meter Name	No.	No.	State of Meter	000 Cu. Ft.
First Date Gas was Used by Meter		19 .	By Flat Rate	19
Drillers				
Dressers				
Signed	Date	19 .	Commencement Notice No.	

☞ Notice all Remarks concerning this Location, Rig, Drilling Outfit, Drilling Conditions, Fuel and Water Supply, should be Noted on the Back.

Practical Form No. 6

THE DRILLING COMPANY

Completion Notice—Drilling Department

Lease No. Name Well No Serial No.

Township County, State of

Was Completed 19. Packed in 19 . Accepted 19

Packers Used Packer Rubbers Destroyed

Shot: No. Shells Length Top Ft. Bottom Ft. No. Quarts

Sand Producing.	Amt. Sand.	Size Tubing.	1 Minute.	2 Minute.	3 Minute.	4 Minute.	5 Minute.	10 Minute.	Rock Pressure.	Line Pressure.	Total Depth, Feet.	Volume Cubic Feet.

Meter Name No. No. State of Meter 000 Cu. Ft.

Meter Name No. No. State of Meter 000 Cu. Ft.

Last Date Gas was Used by Meter 19 . By Flat Rate 19

Drillers

Dressers

Signed Date 19 . Completion Notice No.

☞Notice all Remarks Concerning this Location, Rig, Drilling Outfit, Drilling Conditions, Fuel and Water Supply, should be Noted on the Back.

It is the duty of the driller, one which is quite often hastily done, to keep a record or log of the well. This consists in noting the various formations drilled through, the casing points, and the showings of water, oil or gas. The importance of good logs cannot be overestimated. The accuracy with which these records are kept determines the accuracy of the convergence sheet. The points where oil and gas showings are found must be known as it may become desirable to shoot such showings and in order that it may be done properly the exact distance from the top of the hole must be known. Measurements should be made with a steel tape made for that purpose.

A typical well record will show the various lengths and sizes of the casings; the points where water and cavings are encountered as well as the various sands and formations drilled through. The driller may be able to determine the kinds of strata that are being penetrated; experience is the best teacher for this, but we may put down one or two characteristics that may be noticed which will help to determine the kind of stratum is being struck by the bit; thus a rapid letting out of the screw shows that soft rocks, such as shales or coals are being drilled, while the opposite would indicate that the stratum is hard. The drill, when pulled out, will have a muddy appearance when drilling through soft, clay-like material, and a polished stem and bit when hard shale is being cut up, while solid hard formations will roughen the bottom of the bit, the "feel" of which will indicate such a condition.

The oil man's vocabulary contains the word "shell," which must be carefully understood, as it is rather loosely used by the driller. The meaning of the word in this connection is applied to any comparatively thin and hard formation. Thus it may be a thin limestone or sandstone or hard shale; anything that will retard the drilling tools for any length of time. It means very little ordinarily, except that a hard stratum was found. Many records show the following: "No sand found, its place taken by a shell." Such information is rather loose and must

be guarded against. Of course the best method of knowing what has been drilled through is by examining the bailings as they come up from the well; whether it is a shale or sandstone or limestone can easily be determined. Quite often dark shales are mistaken for coal.

CHAPTER XIV

"BRINGING IN" WELLS

In a strictly "wild-cat" country, only the geological information gathered in the field may be employed as to the proper horizon that is looked for. In most instances, however, although wells are some distance from production, the various strata are well known and the formations recognized from past experience.

From the elevation of the well, which has been determined at the time the well location was made and surveyed, the depth at which the sand is expected may be figured very closely. As the drill approaches the sand, the samples from the bailer are carefully washed and laid out in order, the operator and drillers are enabled to tell from such samples when the top of the sand is reached. A steel line measurement should always be taken at this point, and the drilling proceeds. It is customary, especially in an unknown country, to be prepared for the possibility of striking a large volume of gas, by laying a snuff-line from the boiler to the mouth of the well; in case gas is struck unexpectedly, the steam under pressure from the snuff-line is turned on so that it mixes with the gas and disperses it, so that the risk of fires may be minimized. All fires around the rig are to be extinguished at once, the boiler allowed to cool and moved to a safe distance. The direction of the wind is always to be watched, as it may blow in the direction of the boiler, and gas with it will be a source of danger.

When the top of the sand is reached and its depth determined, the drilling is resumed. The presence of gas may be noted at the well mouth and is to be gauged after each "screw" with the Pitot-tube. The presence of oil is determined by noting the contents of the bailer, in which it will be brought up if there is any present. Water is to be watched for and if the sand's color changes and turns white, water is indicated. If there is oil in the hole the

water is not to be drilled into more than a foot, so that the incoming water will not be too much and yet sufficient to move the oil with it, thereby bringing a larger amount of oil into the hole. The size of an oil well can be estimated only at the time it is drilled in. This may be done by noting the rapidity with which oil fills up in the hole, as noted on the drilling rope, when the tools are withdrawn; the space taken up by the tools as well as the possibility of water being under the oil must be considered. The amount of oil flowed, swabbed or bailed out during the first twenty-four hours is the general report that is given out in most cases.

The surest method of valuing an oil well is after it has been pumped or allowed to flow for some time. In the case of large gushers, the amount of oil produced is known only if properly tanked. The production of oil out of a new well is known as its flush production, and in the course of some time, varying from six months to a year, a well will settle down, and when it is known to have a settled production. Wells are generally bought and sold with the settled production in mind.

Very little can be told from the examination of the sand brought up in the bailer; however, whether it is soft or hard and the shape of the grains as well as their size may be determined. When water, especially hot water, is poured on the sand, the rainbow colors of petroleum may be seen if any amount is present. Oil men consider all sands that produce oil as good sands, and others as "no good." Although in the true sense of the word all this is true, still the appearance of the sand may explain the bad results of a well, and although this may be a post-mortem information, it may be put to good use in future drilling, by noting the variation of the texture of the sand from place to place, and as such variations may take place gradually, such knowledge is worthy of consideration.

A sand body may have one or more pay streaks, which are generally divided by a closely cemented portion of sand, or by thin shale stratum; such conditions are indicated by the drillers as breaks. Breaks may divide a sand into several pays, or again it may be the dividing point between oil and water.

PRACTICAL FORM NO. 7

WELL RECORD

THE COMPANY

DRILLING DEPARTMENT

Lease No. Name Well No. Serial No.

Township County, State of

Covering Acres in Section No. Lot No. District Field

Bounded on the North by East

South West

Location Feet from and Feet from

Contractor

Address

Company Operating

Location Received 19 . Location Made 19

Rig Commenced 19 . Rig Completed 19

Commencement Notice No. Completion Notice No.

Drilling Commenced 19 . Drilling Completed 19

Packed 19 . Depth Packed at Feet from bottom

Accepted 19 . By

Drillers

Dressers

Rig Builder Address . Rig New or Old

Fuel Used Purchased from

Price Amount $

Meter Name No. No. Date Con. 19 . State 000 Cu. Ft.

Meter Name No. No. Date Discon. 19 . State 000 Cu. Ft.

Remarks: Amount Consumed 000 Cu. Ft.

Meter Name No. No. Date Con. 19 . State 000 Cu. Ft.

Meter Name No. No. Date Discon. 19 . State 000 Cu. Ft.

Remarks: Amount Consumed 000 Cu. Ft.

Estimated Production per day when first drilled in Cu. Ft. Total Amount Consumed 000 Cu. Ft.

Oil Flowed Barrels. Bailed. Barrels. Swabbed Barrels. Pumped Barrels

Practical Form No. 7—*Continued*

GAS WELL OPEN FLOW

Sands Producing.	At Center.		At 1-7 Diam.		Size Casing.	Size Orifice.	Mercury, Inches.	Water, Inches.	Flow, Cu. Ft. 24 Hours.	Rock Pressure.	Total Depth.
	Pounds.	Ounces.	Pounds.	Ounces.							
											Ft.
											Ft.

GAS WELL CLOSED IN

Sands Producing.	Size Tubing.	1-Min.	2-Min.	3-Min.	4-Min.	5-Min.	10-Min.	20-Min.	Flow, Cu. Ft. 24 Hours.	Rock Pressure.	Total Depth.
											Ft.
											Ft.

OIL WELL

Sands Producing.	Size of Rods.	Kind of Rods.	Working Barrel.				Capacity, Barrels 24 Hours.	Remarks	Total Depth.
			Kind.	Size.	Length.	Stroke.			
									Ft.
									Ft.

WELL SHOT

Sands Producing.	Top of Shot.	Bottom of Shot.	No. of Shells.	Length of Shells.	No. of Quarts.	Results or Remarks.	Total Depth.
							Ft.
							Ft.

WELL ABANDONED

Sands Not Producing.	Reason of Abandonment.	Abandonment Notice No.	PLUGGED.		Plugging Notice No.	Material Used in Plugging.
			Bottom Ft.	Top Ft.		

Remarks:

WELL DRILLED DEEPER

Sands Found.	Top.	Bottom.	Amount.	Depth where Flow Occurs.	Quantity Gas, Oil, Water.	Total Depth.
	Ft.	Ft.	Ft.	Ft.		Ft.
	Ft.	Ft.	Ft.	Ft.		Ft.
	Ft.	Ft.	Ft.	Ft.		Ft.

PRACTICAL FORM NO. 7—*Continued*

Material.	Size.	Weight.	Kind, Style or Make.	Put in Well.	Taken Out of Well.	Left in Well.	Cond.
Conductor							
Drive Pipe							
Drive Pipe							
Drive Shoes							
Casing							
Casing							
Casing							
Casing							
Casing							
Casing							
Casing							
Casing Shoes							
Casing Shoes							
Tubing							

Tubing							
Anchor							
Packer							
Packer							
Working Barrel Pumping Rods							
Anchor Clamps							
Gate Valves							
Gate Valves							
Swage Nipples							
Nipples							
R. & L. Nipples							
R. & L. Couplings							
Plugs							
Tees							
Ells							
Street Ells							

PRACTICAL FORM NO. 7—*Continued*

WATER WELL

Material Used.	Size.	Weight.	Kind, Style or Make.	Put in Well.	Taken Out of Well.	Left in Well.	Cond.

Remarks:

DRILLERS RECORD

Formation.	Top Feet.	Bottom Feet.	Thickness Feet.	Remarks.	Date.

IMPORTANT NOTICE.—All important formations or conditions affecting this well must be noted above. Give actual depth at which any Oil, Gas or Water appears. If increase occurs in any Sand, repeat name of Sand and show increased flow.

If a well of promise is obtained the next consideration is the shooting of the well. This operation consists in lowering a certain amount of nitro-glycerin in a tin shell with sufficient amount of it to fill up the entire distance opposite the pay streak or sand; it is then exploded by dropping a time fuse or sometimes by the old fashioned go-devil; the object being to shatter the pay sand, thereby increasing the flow of its contents. The amount of nitro-glycerin put into a well depends upon the thickness of the sand and the diameter of the hole at that point. The attempt is to shoot all of the sand. If water is present in the sand below the oil the shell is so placed that the sand lying above the water is shot, so as to avoid increasing the amount of water as much as possible. When only a few feet of pay sand is found it is sometimes customary to place a "dump-shot" with the regular one, which is done as follows: after the nitro-glycerin shell is in place, another shell filled with nitro-glycerin is lowered, but when reaching the bottom its contents are allowed to escape, "dumped," thereby increasing the amount of shot that might be placed in the hole.

A dolomitic limestone will stand almost any amount of shooting, and many wells, apparently dry, have been made producers by shooting. Soft sands do not show good results from shooting and the loose or unconsolidated sands are not shot at all. Wells which produce a large amount of oil naturally should not be shot until they cease to flow. In this way a large amount of oil may be obtained without the danger of the well being ruined by shooting, as shots will work both ways, and although in the majority of cases they bring good results, still, there are many instances where wells have been ruined by shooting, as it may have liberated a large amount of water, or sealed off the pay portion of the sand, and it is also possible that the casings may be shot into, either fracturing them and allowing water to come in and drown out the oil, or the casing may be so bent and plugged as to form a bridge which necessitates expensive fishing operations, which if unsuccessful would mean the abandonment of the well. Whether the shooting of a well may be deferred depends upon the existing conditions; thus if a neigh-

boring property is producing oil, it will require similar tactics upon the part of the operator to put his well also in condition to prevent the opposing operator from draining the territory without opposition.

All wells that are non-productive or those that have so declined as to be no longer a commercially valuable producer, should be plugged. The methods of plugging are similar in most fields. Many States require certain methods, and especially in a coal-producing State, the plugging requirements are strict, as coal beds are to be protected. In many cases a permit is first to be applied for, and the well plugged in the presence of of an inspector appointed for that purpose. Plugging is desirable, whether enforced by regulations or not, as it will prevent the flooding of the sand from sources outside of it, and keep the rock pressure from declining.

The drilling of wells in a territory where large wells are expected necessitates various controlling devices with which big flows may be checked and properly capped or shut in. These devices vary in different localities and there are many good appliances on the market which may be used.

CHAPTER XV

COMPLETION OF WELLS

After a well is "brought-in" and classed as a producer, the well is put in shape for production. Gas wells require that a string of tubing be set, in most cases its bottom being above the sand with a packer to prevent the entrance of all foreign material in the well. The size of the tubing depends on the size of the wells; very small ones need only 1-inch tubing, the most common size in use being the 2-inch, and for large wells 3- and 4-inch tubings are used. In case of gusher wells, it is impossible to lower a string of tubing and such wells are shut in the casing, and when they decline, tubing may then be inserted. In some instances it is possible to pull the casing, leaving only the tubing in the hole. Gas wells should be equipped with at least two gates, one for shutting off the well from the line, the other used for blowing and gauging purposes. (Fig. 116.) If for some reason or other a well is "making" water it is necessary to eliminate it to prevent it from ruining the well. Such water is removed by allowing the well to blow open, the sudden release of the pressure bringing the water with it. At the time of blowing wells the pressure should be taken as well as the general behavior of the well noted. Many wells need agitating before the water may be lifted; this is done simply by lowering a weight on a line, which will agitate and flow the water. Quite often the sudden release of large pressure will freeze up gas wells; in such cases the volume and pressure are lower than usual; it is

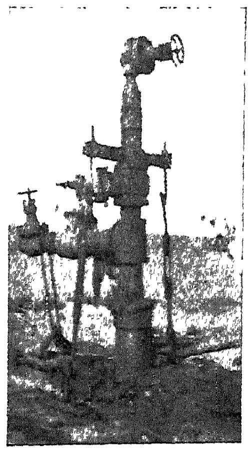


Fig. 116.—Gas Well. (Catalog Metric Metal Works.)

only necessary to shut the well in and it will thaw itself out in a short time. In many instances a gas well may salt up and this condition seems to occur mostly in sands that do not carry water, or very little of it. This may possibly be due to the fact that the original connate water having been lost, some of its contents may have been deposited in the sand, which when brought into action by the movement of gas may entirely clog the pore spaces. Many wells are entirely lost, ruined by salting.

All gas wells should be equipped with drips, the purpose of which is to catch water or oil and prevent it from getting into the lines. Drips generally consist of a few joints of larger sized casing placed on the line at the mouth of the well, the direction

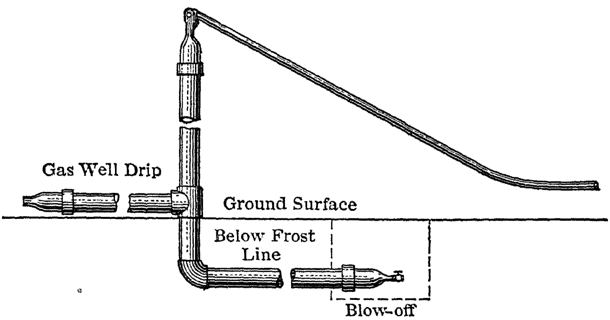


FIG. 117.—Drip. (Catalog Metric Metal Works.)

of the gas flow being changed, thus causing the dropping of foreign elements in the drip. (Fig. 117.)

The chemical analysis of all waters encountered during the drilling of the wells may be used in determining the probable source of water with the gas.

Meters are placed between the wells and the gathering pipe lines to show the amount of gas the well is able to deliver against the pressure carried on the line. Meters are often omitted by gas companies who drill their own wells and carry the gas through their own pipe lines, if the lease calls for a certain specified sum as well rental to the property owner. If the lease specifies a certain percentage of the gas as a royalty, then the volume obtained is measured.

P.F. No. 8

COMBINED OIL RUN TICKET

MONTH OF

OIL FROM **WELL** **TANK No.**

DATE		TICKET NO.	GAGE		IN TANK				LOSS		NET RECEIPTS		RUNS	
TOTAL														

Construct decline curve from this data

Practical Form 8.

Oil wells need entirely different methods of handling, and unless a gusher well is completed, all wells require a cleaning-out process after the shot to remove all the accumulated debris. After cleaning out, the well is tubed similarly to gas wells, only packers are often omitted if the well is to be pumped, as any

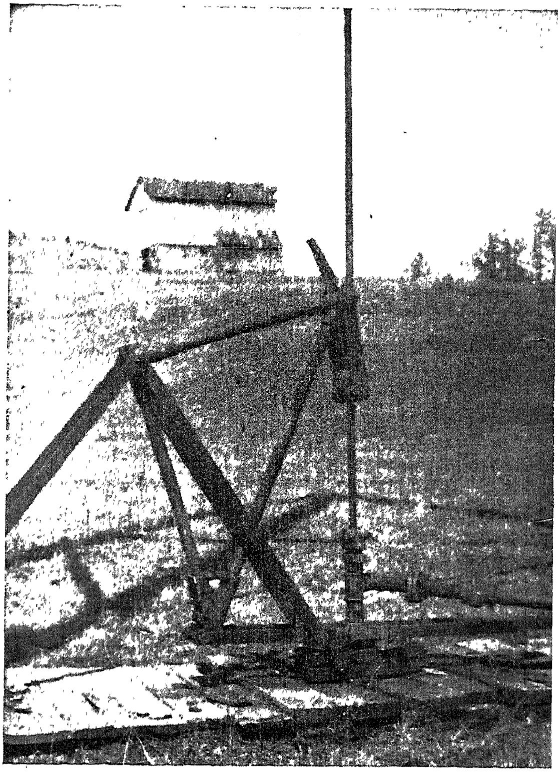


FIG. 118.—Pumping Jack, used for Pumping Shallow Wells.

water that may find its way down into the sand through the hole will be pumped out with the oil. It is customary to drill a pocket below the pay, in which sediments may accumulate, especially those caused by shooting. The lower joints of the tubing are perforated, allowing the entrance of oil into it, through which the oil is pumped by means of valves in a working-barrel, raised and lowered by sucker rods which are attached to a power

WELL COMPLETION NOTICE

		Elevation
		Acres
		Location Survey

Top of Sand
Bottom "
Total Depth
Tubing inch
Packer at
Size of hole below Packer
Depth " " "
Casing
Casing
Casing
Pocket below Sand
Shot Qts.
Top of Shell Bottom
Anchor

Date 19

Sec. Township County State

Drilled by Lands of Lease No. Well No.

Remarks

	Flowed	Bailed	Swabbed	Produced 1st 24 hrs.	Estimate Prod.	Water
OIL WELL						

	Size Opening	1 Min.	2 Min.	3 Min.	4 Min.	5 Min.	10 Min.	Rock Pr.	Inch Water	Inch Merc.	Lbs. Gauge	Open Flow	How long blown open
GAS WELL													

Practical Form 9.

at the surface. In instances where the bottom of the last string of casing is a considerable distance above the sand a sufficient number of joints of casings are inserted that fit inside the long string casing, and reach from the bottom of it to the sand, this extra lower string of casing being known as the liner, and its

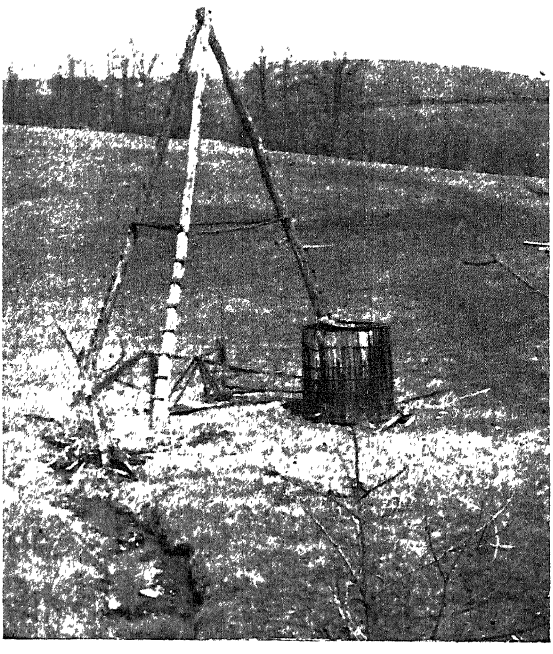


FIG. 119.—Shallow Well Fitted up for Pumping, with Flow Tank Alongside.

object is to protect the walls of the hole between the last casing point and the sand.

In a shallow field the different wells are pumped with one power in common for many wells, the sucker rods in the wells are lifted, and allowed to drop back by their own weight; they are attached to pumping jacks (Fig. 118) which impart the motion to the sucker rods from the power with which it is con-

nected with shackle-rods. Very deep wells require a separate pumping power for each well, for which the original drilling power may be used, or a gas engine installed. If sufficient amount of gas is present with the oil it may be separated from the oil by means of a gas trap installed at the receiving tank, and the gas used for fuel on the lease or elsewhere.

Considerable difficulty is offered by the formation of paraffin in the well, which will clog up the pores of the sand as well as obstruct the passage of oil in the tubing. The common practice is to pull out the rods and properly clean them as well as the hole. If the original derrick has been dismantled, as in the case of most moderate depth fields, a portable cleaning-out outfit is used, which may readily be set up over a well, and the necessary pulling done by a team of horses.

As a well is being pumped the oil is carried through one or more lead lines to the receiving tank. It is customary to use two sets of tanks, the first to collect the oil, water and whatever sediments may be brought up by the pump (flow tanks) (Fig. 119); the sediments and water are drawn off through drain holes located near the bottom of the tank, and the oil is run into another tank (receiving tank). The oil on a large lease is collected at several places and from the various points brought by gravity to the main tank, from which the purchasing company runs the oil into their pipe lines, after having drawn off the water and sediments and gauging the amount of oil thus stored.

CHAPTER XVI

GAUGING OIL AND GAS WELLS

A REPRESENTATIVE of the purchasing company known as the gauger determines the amount of oil that is in the tank. After the water and sediments have been drawn off, he inserts a rod graduated to quarter inches, by means of which the number of inches of oil in the tank is found. This information enables us to compute the number of barrels in a tank if its exact size is known. Tanks used for such purposes are measured or "strapped" by the purchaser's engineer, who determines the size and computes a table from which the number of barrels per inch can be calculated.

Wooden tanks built up of staves and held together by means of hoops when moved about and set up at various points will not be the same size at all times, and for this reason it is necessary that all tanks used for gauging purposes should be strapped. When the measurements have been made the tank is numbered, and the position of the hoops are clearly marked by a white-washed line so that if any of them are displaced they may be noticed. As wooden tanks are smaller at the top than at the bottom, the amount of oil at a distance of one inch will vary and be more at the bottom than at the top. For instance, in a 250-barrel wooden tank, an inch of oil at the top will indicate about $2\frac{1}{4}$ barrels of oil; at the bottom about $2\frac{3}{4}$ barrels; for a rough estimate $2\frac{1}{2}$ barrels of oil per inch may be considered a good average. Iron and steel tanks being cylindrical the ratio of the number of barrels per inch will be the same at any point.

The gauger determines the temperature and the number of barrels of oil in the tank and allows the oil to run into the line, in which the oil is carried either by gravity or pumped to the storage tanks. It is advisable to run the oil at as frequent

intervals as possible to prevent the evaporation of large amounts of oil. The producer is given a memorandum (Fig. 120) and a similar one is retained by the gauger and turned in at headquarters. In the winter many oils become so heavy that it is necessary to "steam" them before they can be run.

Dist. No. ____________ Date ____________

Ticket No. ____________

____________ Owner

Well Nos. ____________ Total ____________

Tank No.	OIL	1st	Feet	Inch	Office Calculat.
Size		2nd			
Steamed ______ Deg.	B.S.	1st			
		2nd			
Cold	Water	1st			
		2nd			

By ____________

Station ____________

Old Seal No. New Seal No.

Operators Check

Time	1st Meas. ____________
	Gauger
	Owners Witness
	2nd Meas. ____________
	Gauger
	Owners Witness

FIG. 120.—Oil Run Ticket.

The volume and efficiency of a gas well depends upon the static and dynamic pressures existing in a well. The dynamic pressure, which is the open flow volume is measured with a Pitot-tube, which is a U-tube, equipped with a scale of inches

divided into tenths, the zero point being half-way along the tube and the graduations extending in both directions from it. The tube is filled with water or mercury so that the level of the liquid on each side of the scale will be at zero. (Fig. 121.) By means of proper adjustable fittings the gauge is held over the

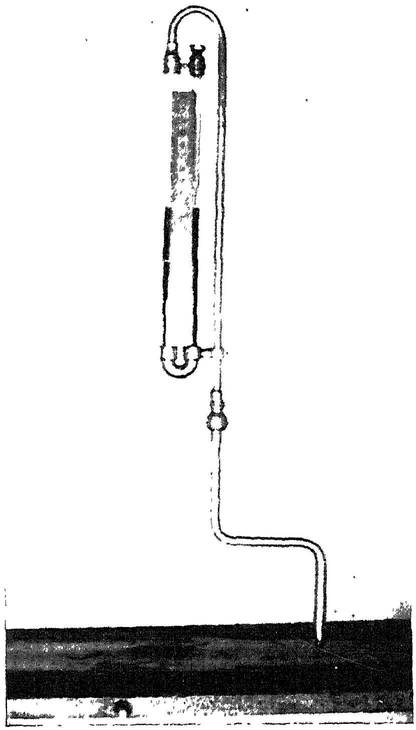


FIG. 121.—Pitot-tube or U-gauge.

escaping gas from the well so that the pressure of the flowing gas may be indicated by the distance between the different levels of the liquid in the U-tube caused by such pressure. By referring to a table the size of the gas well's volume may be computed if the diameter of the opening of the well mouth is known.

The static pressure, which is the so-called closed or "rock-pressure," may be determined when the well is properly fitted up so that an ordinary steam gauge (Fig. 122) may be so connected that it will indicate the pressure of the well. The rock pressure of a well is the ultimate pressure that is recorded by such a steam or spring gauge.

The actual procedure in measuring the open flow volume of a well is as follows: allow the well to "blow off" to its natural pressure, hold the Pitot-tube or U-gauge on level with the top of the opening about one-third of the way in; note the number of inches between the levels of the liquid on each side of the tube, also determine the size of the opening. For instance, if the liquid which we are using in the tube is water, and is held over the flow of gas, we note that the liquid has been depressed five inches on one side and raised five inches on the other the total distance between levels will be ten inches, and the size of the casing through which the gas is escaping is four inches in diameter, then referring to our table, under ten inches of water through a 4-inch opening we find the figure 1,904,640, which will be the number of cubic feet of gas flowing out of the well in twenty-four hours. If mercury instead of water is used, the same number of inches of mercury through a 4-inch opening will be seen to be 7,038,720 cubic feet per twenty-four hours. If the size of the well is too great, so that neither water nor mercury can be used, the steam gauge may be employed by holding it over the opening in the same manner as we hold the Pitot-tube; the volume of the well may be determined by noting the number of pounds indicated by the gauge, and the volume computed from the table similarly as with water and mercury. Thus if the gauge indicates 25 pounds through a 4-inch opening, the volume will be shown by the table to be 13,678,080 cubic feet of gas per twenty-four hours.

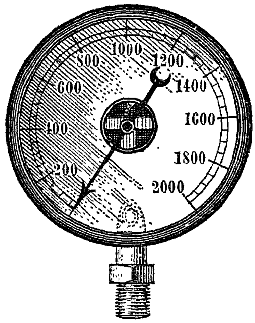


FIG. 122.—Steam or Spring Gauge.

To determine the closed pressure of a well it is best to allow the well to blow down to its natural pressure also, that all the water in it may be blown off, which otherwise would retard the gas; then the steam or spring gauge is to be screwed in place and the well shut in, then the pressure noted. It is customary to note the number of pounds pressure as indicated by the gauge at the end of each minute for several minutes, also noting the final pressure, which in some wells may be reached in a few minutes, while in others it may take twenty-four hours or more before the total pressure is obtained. This will be the closed or rock pressure of the well.

The pressure of a well at the end of the *first minute* may also be used to estimate the open-flow volume of a well and a close approximation may be obtained by the following method: add 15 pounds to the gauge reading, then multiply by the depth of the well, times one-half the square of the diameter of the tubing in the well; the resulting figure will be the volume of the well. This approximation will in all cases be less than the actual volume of the well. If the diameter of the tubing is not constant the entire depth of the well, separate calculations must be made for each different diameter to the entire depth of the well, and the separate results are to be added together.

In order to realize the value of a gas well one must have a thorough understanding of the difference between open-flow volume and closed pressure. It is a common occurrence to hear people say that a well is a big one, as the pressure is 500 pounds to the square inch; and this is the most common information one hears about gas wells, and such data are of no value unless the open flow volume is also obtained. It has been stated in another chapter that the rock pressure has a certain relation to depth, and it will be noticed that in a new field wells in the same sand will have approximately the same rock pressure; and of two wells offsetting each other, one may make 100,000 cubic feet of gas per day, and the other 5,000,000 cubic feet during the same time; both will have the same rock pressure, yet one is a big well and the other very light. Of two wells having the same open-flow volume but different pressures, the one with the greater

TABLE IV

CALCULATED OPEN FLOW VOLUME OF GAS WELL, FROM FIRST MINUTE PRESSURE

P = Pressure;
C = Constant (15 lbs.);
L = Length of hole;
D = Diameter of hole;
V = Volume.

Formula

$$(P+C)\times L\times\frac{D^2}{2}=V.$$

More accurate results will be obtained if the following figures are used for $\frac{D^2}{2}$ (which are somewhat larger):

For a diameter of	use		use
1″	.55	$5\frac{5}{8}$″	17.26
2″	2.19	6″	19.63
3″	4.91	$6\frac{1}{4}$″	21.31
$3\frac{1}{4}$″	5.76	$6\frac{5}{8}$″	23.94
4″	8.73	$7\frac{1}{4}$″	28.67
$4\frac{1}{4}$″	9.85	8″	34.91
5″	13.64	$8\frac{1}{4}$″	37.12
$5\frac{3}{16}$″	14.14	$9\frac{5}{8}$″	50.53
$5\frac{1}{4}$″	15.03	10″	54.54

EXAMPLE. The total depth of a well is 1250 feet and finished up with $5\frac{5}{8}$-inch hole. Bottom of 2-inch tubing 120 feet above bottom of hole, total length of tubing therefore 1130 feet. Spring gauge pressure at the end of first minute 320 lbs. Calculate open-flow volume of well from these figures.

$$(P+C)\times L\times\frac{D^2}{2}=V;$$

(1) 2″ tubing $320+15\times 1130\times 2.19=$ 829,025

(2) $5\frac{5}{8}$″ below tubing $320+15\times 120\times 17.26=$ 693,852

1,522,877 cu. ft. per 24 hours.

pressure will feed more gas onto a gas line than will the other, and therefore will be more valuable. Pressure is required to put gas on a line which also has a pressure, and high-pressure gas lines may carry from 100 to 300 pounds of line pressure, and in order that a well may put gas on that line it will have to have a greater pressure than that of the gathering line. It must also be remembered that the volume of a gas well as determined by the Pitot-tube will not be equal to the volume that it will put on a line against pressure; such a volume depends upon the size of

the well, its rock pressure and the line pressure against which the well is working.

Where large operators use gas compressors, the volume of a well is the main consideration, as the compressors enable the keeping of the line pressure down, allowing wells with small rock pressure to deliver their gas onto the line.

Wells are in the care of well blowers, who visit each well frequently, and note the pressure as well as blow off accumulated water and watch the actions of the well.

A word of caution against the ordinary information gained regarding the size of gas wells, as the smallest volume well will make considerable noise or whistle if suddenly opened up after being shut in for any length of time, and such action will convey the impression to the uninitiated that it is a large well, but that may not be the case and all such information should be verified wherever possible by allowing the pressure of the well to blow down and then properly gauging it. Small and shallow wells when left open for one-half or one hour will blow down sufficiently for proper gauging. Deeper and larger wells should be allowed to blow anywhere from six to twenty-four hours, as it may be possible that it will take all that time for it to blow down; sometimes gas may find lodgment in an upper sand and until such a sand is exhausted the true volume of the producing sand cannot be determined.

Never gauge a well through an opening in a gate, as such openings are not as large as the size of the gate would indicate. Thus a 2-inch gate's opening will not be circular, but in the neighborhood of one inch by two inches long; try to keep considerable distance from any fittings, and it is best to carry a 2-inch nipple or better still a 2-inch pipe and gauging through that.

CHAPTER XVII

INCREASING PRODUCTION

In an attempt to get the full benefit of the oil or gas in the pay sand, it requires careful attention and the employment of such handling as will bring the desired results.

The ordinary methods require that the wells be taken care of in a proper manner, and under such handling the production from oil wells is obtained so long as the gas pressure is sufficient to move the oil from the rocks into the well. When the ordinary methods fail in further production, various means are at hand with which an increase in the production may be brought about.

From the facts mentioned in connection with the theoretical and the effective porosity, it will be noted that only a small percentage of the total amount of oil in a given sand is removed, while the greatest portion of it will remain in the sand owing to the fact that the general method of recovery, which is by means of pumping, is not sufficient to recover the total amount of oil from the sand. As long as gas pressure is greater than the ordinary atmospheric pressure, such pressure will move the oil towards the opening, but when it has declined so that it is unable to bring the oil with it, several systems are put in use in order to assist or reproduce the pressure previously existing in the sand. For this purpose the various processes that have been employed are: the use of vacuum, flooding, introduction of compressed air or compressed gas; in each case it will be noted that the resulting pressure is the main factor that is employed.

One of the oldest methods is the application of vacuum, by means of which the pressure at the wells is decreased, which allows the gas that may be in the oil to expand and work against smaller atmospheric pressure, thereby permitting the flow of oil

into the well. Although production may be increased by this method its effect, however, is but temporary and the only reason for its employment is the fact that the increased gas production may be utilized for gasoline, as such gases are higher in gasoline content than the original casing-head gas, the other item being the increased production of the oil.

Flooding has been employed in several instances, the most

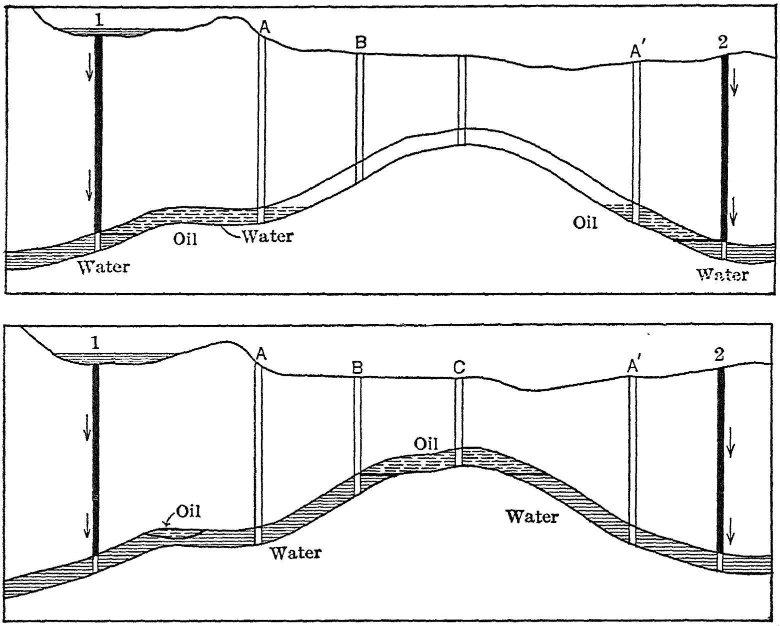


FIG. 123.—Effects of flood water and arrangement of wells drilled to utilize flood water pressure. (Bureau of Mines Technical Paper 51.)

notable being the case of Bradford, Pa., where the system has been used with success, and the increased production of oil is obtained by allowing water to enter the sand, generally through a well down the dip, and as the sand is being filled with the water the oil is gathered in front of it and carried further up the dip into the wells that are located there. (Fig. 123.) The system is not recommended very highly, not only as it has been used successfully in but one case, but also because the flooding will

practically end the usefulness of such a sand, and as other methods of greater promise may be tried that offer a chance for greater increase in production but which cannot be used after the sand has been so flooded.

Another method in which water also plays a part has been patented by R. H. Johnson (Patent No. 1,083,018), which consists in drilling the hole through the oil sand into the water sand (where both occur in the same reservoir and the pressure

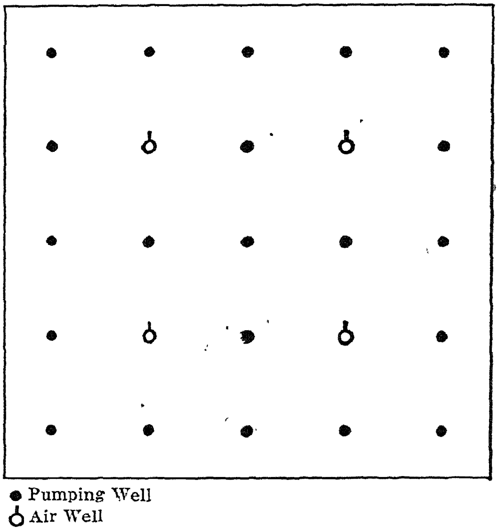


FIG. 124.—Diagram showing distribution and spacing of air and pumping well under ideal conditions on a square 160-acre tract. (Bureau of Mines Bulletin 148.)

has been reduced). Then by pumping rapidly a cone-shaped gradient is set up in the water table around the well, which will aid the movement of oil inward. (Johnson and Huntley, "Principles of Oil and Gas Production.")

The most successful method so far employed is the introduction of air or gas under pressure into the sand through small or abandoned wells properly fitted up to take the compressed gas, or air (air holes) (Fig. 124) and an attempt in reproducing the rock pressure in the sand is made. The air or gas, being under

pressure, will force the oil through the sand and into the wells. The use of air or gas depends upon the circumstances that may exist, and both have their advantages and disadvantages.

In the case of gas, it is best employed where a large amount of it is on hand, otherwise the process would be expensive; its point in favor, however, is the fact that a gas so introduced may be regained and be richer in gasoline contents, which may be removed and the gas utilized again and this process repeated; that is, a gas from some well may be compressed and introduced into the wells and recovered richer in gasoline, the gasoline extracted, the gas again compressed and used in the wells again, sent through the same process.

In case where compressed air is used instead of gas, naturally air is easily procurable and compressed under most every condition. The disadvantage lies in the fact that any gas remaining in the oil will be rendered valueless for gasoline or any other purposes if mixed with the compressed air, and the gravity of the oil as well, may be lowered.

The value of both methods is the greatest when used in a porous lenticular bed, and in such cases production that has fallen down to a barrel has been increased and in many cases a production of 30 or 35 barrels per day has been obtained. Another disadvantage of the process is the fact that it is impossible to control the action of the compressed gas or air in the wells, thus the adjoining property may reap as much benefit from it as the installer, and there are instances where the user of the system did not reap the benefit of his work, while another lease at considerable distance has been greatly improved. Sometimes the current of air or gas will find a short cut or "break through" without going through the required sand; in such cases the air or gas is used without good results. The methods have proved of great success in porous lenticular sands, but without much success in limestone.

The gas or air is compressed and sent through the air holes into the sand and this process is kept up at all times without stopping. In some cases the looked-for results have been noticed in a few hours after the installation of the plant, while in others

it showed good effects only after months of continued work, but it may be said that the advantages greatly exceed the disadvantages, and so far it is the most promising method devised. It is claimed that it has proved of value in 75 per cent of the cases employed. So far the system has been used mostly around the southeastern part of Ohio, having originated around Marietta, Ohio, and is known as the Smith & Dunn process, after the originators, who have installed many plants and put the process to practical test.

In case of increased recovery of gases, we have fewer methods at our disposal, inasmuch as, when a gas well so declines that it necessitates artificial methods of increasing the output of wells, such wells are really of no great value; however, the vacuum method, used similarly as employed for oil extraction, has been tried, but without much success, and can best be used only in connection with a gasoline proposition. The use of vacuum has been in courts in various parts of the country and its legal standing is not clear even at the present day.

The only practical method is the storage of gas, which is really not an increased recovery method, but consists simply in the storing of gas in abandoned wells, through which it is stored in the exhausted sands, so that in case of heavy gas consumption the storage wells may be utilized to assist the producing wells, so that the two used together may supply sufficient gas during a cold spell wherever needed. (Fig. 125.) This method has been discussed by the writer in Bulletin 145 of the American Institute of Mining Engineers, and the other methods above described have been explained at length by J. O. Lewis in Bulletin 148 of the Bureau of Mines.

In this connection the recovery of oil from shales may be mentioned. Great deposits of shales have been prospected with view of obtaining oil from them by a method of destructive distillation, in hopes that the source of oil supplies of the United States may be increased. Along these lines V. Ziegler says:* "These shales do not actually carry oil or gas as such. They contain organic materials such as partially altered plant remains

* Victor Ziegler, "Popular Oil Geology."

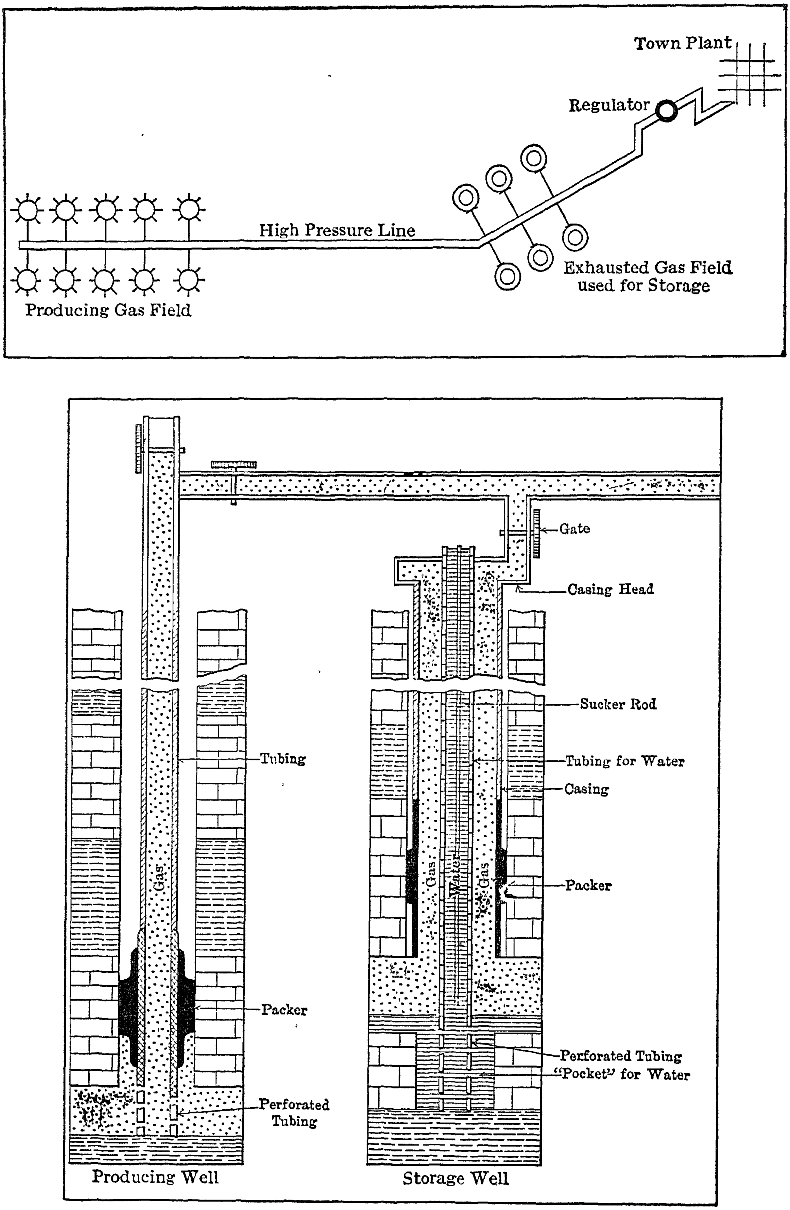


FIG. 125.—Principle of Natural-Gas Storage. (L. S. Panyity in Bulletin 145 American Inst. of Mining Engineers.)

which are broken up into oil and gas when subjected to heat." This is really a manufacturing process and devoid of the uncertainties of the oil producer, and for the purpose of producing

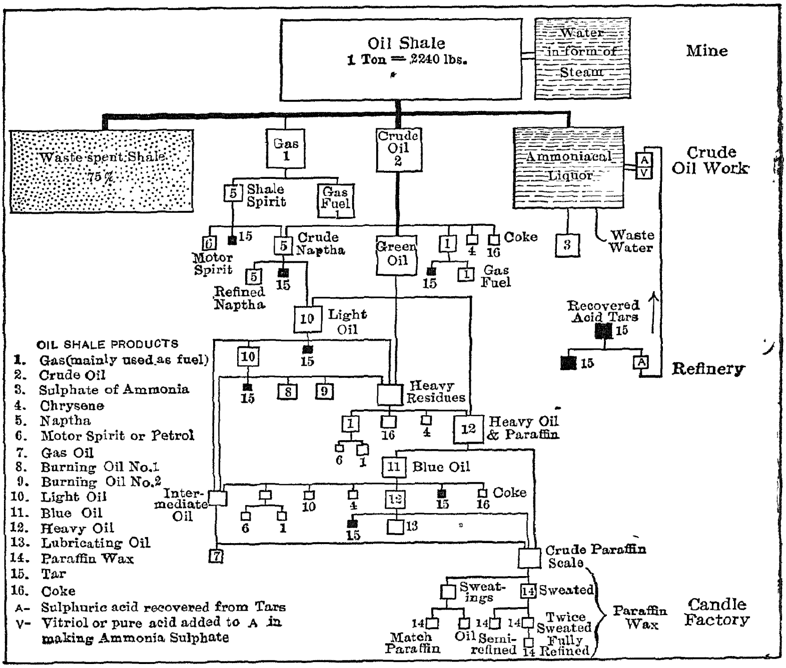


FIG. 126.—Diagram illustrating processes of manufacture in the Scottish mineral-oil industry. (U. S. G. S. Bul. 691-B.)

oil in that manner or in investing in such enterprises it should not be confused with the well-known oil and gas producing methods. (Fig. 126.)

CHAPTER XVIII

THE PRODUCER AND LANDOWNER

THE relation existing between the petroleum miner and the land owner is the same as that of one business man to another. The producer believing that certain land may be of value as an oil or gas prospect will make arrangements with the owner of the land according to terms that may be mutually agreeable.

Although different processes are in existence, such as drilling upon government land, or claims, or upon lands of people over whom the government holds a position of guardianship, still, in the majority of cases the arrangements that take place are by means of the leasing process or by buying the property outright. In the leasing process an agreement is reached between the prospector and the landowner wherein the prospector agrees to either drill a well within a stipulated time, or pay a fee, generally per acre until such a well is drilled, and if not, the lease is to be surrendered by him. For this privilege he agrees to give the landowner a royalty, generally one-eighth of the oil produced from wells on his land if it be an oil well, and in case of gas wells, he may pay a well rental of so much per year, or sometimes he pays according to the size of the well, and such payments are to continue and all royalty be paid during the commercial life of the wells.

Naturally, the value placed upon a lease varies, thus a property close to production will command a higher price than will one far removed or in "wild-cat" territory. Prices are generally the greatest during an oil excitement, and if large amount of territory is found open around a discovery well, in such cases prices of all kinds are asked and paid during the heat of the excitement, and as good property may be obtained at a small sum, many worthless ones receive fabulous prices. In such

PRACTICAL FORM No. 10

LEASE No....................

OIL AND GAS LEASE

From

....

....

To

THE..............................CO.

Date..19......
Term...Years
No. Acres...
Township..
County..
Received..
at...............................o'clock..................M.
Recorded..19......
in...............................County, ...
Record of Leases, Vol..............................Page..........
....

Recorder.

Recorder's Fee, $...................

RELEASE

THE........................CO., Lessee, having paid to the Lessor one dollar and all amounts due hereunder, and having elected to surrender the within lease and all its rights thereunder, does hereby surrender and cancel the same and hereby endorses its surrender hereon.

In witness whereof, it has hereunto set its hand, this.................

..............................day of..........................

..............A. D. 19......

Witness: THE.....................CO.,

....

.... Per..............................

THE STATE OF.........................
COUNTY OF............................ } ss.

Personally appeared before me, a................................ in and for said County,.. ....who ....acknowledged the signing of the foregoing instrument to be................voluntary act and deed for the uses and purposes therein mentioned.

In testimony whereof, I have hereunto set my hand and affixed my notarial seal this...........................day of................

............A. D. 19........

....

....

THE STATE OF.........................
COUNTY OF............................ } ss.

Personally appeared before me, a................................ in and for said County,.. ....who ....acknowledged the signing of the foregoing instrument to be................voluntary act and deed for the uses and purposes therein mentioned.

In testimony whereof, I have hereunto set my hand and affixed my notarial seal this...........................day of.............

.............................A. D. 19......

....

....

THIS AGREEMENT, made and entered into this ....day of............................, A. D. 191.., by and between.....
....
....................................hereinafter called the Lessor, and......................................, a.................
corporation, called the Lessee.

WITNESSETH: That the said Lessor, in consideration of the sum of one dollar, the receipt of which is hereby acknowledged and of the covenants and agreements hereinafter contained, does hereby grant unto the Lessee all of the oil and gas and all of the constituents of either, in and under the lands hereinafter described, together with the exclusive right to drill for, produce and market oil and gas and their constituents and also the right to enter thereon at all times for the purpose of drilling and operating for oil, gas and water and to possess, use and occupy so much of said premises as is necessary and convenient in removing the above named products therefrom, by pipe lines or otherwise, for a term of twenty (20) years and so much longer thereafter as oil, gas, or their constituents are produced in paying quantities thereon, all of that certain tract of land situate in Section No. ...., Township of.......................................,
County of..and State of...................., bounded substantially as follows:
On the North by lands of.......................................
On the East by lands of..
On the South by lands of.......................................
On the West by lands of..
containing...
(................) acres, more or less, being all the land owned by Lessor in said Township. It being understood, however, that no well shall be drilled within................feet of the barn or dwelling on said premises without the consent of Lessor.

In consideration of the premises the said parties covenant and agree as follows:

Lessee to deliver to the Lessor in tanks or pipe lines one eighth ($\frac{1}{8}$) of the oil produced and saved from the premises and to pay for the product of each gas well from the time and while gas is marketed an annual rental of ....Dollars ($..............), payable annually.

Lessee to drill a well on said premises within......................
from this date or pay to Lessor...................................
Dollars ($................) each................................
thereafter until such well is drilled or this lease surrendered. If a gas well be completed before the end of the term for which rental has been paid for

delay, the unearned portion of said rental shall be a credit on the gas well rental.

Lessee to bury, when so requested by Lessor, all pipe lines used to conduct gas or oil off the premises and to pay all damage to growing crops caused by operations under this lease.

Lessor may lay a line to any gas well on said lands and take gas produced from said well for use for light and heat in one dwelling house on said land, at Lessor's own risk, subject to the use and the right of abandonment of the well by Lessee. The first two hundred thousand cubic feet of gas taken in each year shall be free of cost, but all gas in excess of two hundred thousand cubic feet taken in each year shall be paid for at the current published rates of the Lessee in the town nearest the premises above described and the measurement and regulation shall be by meter and regulators set at the tap on the line. This privilege is upon condition that Lessor shall subscribe to and be bound by the reasonable rules and regulations of the Lessee relating to the use of free gas.

It is agreed that said Lessee may drill or not drill on said land, as Lessee may elect, and that the consideration and rentals paid and to be paid constitute adequate compensation for such privilege. Should it be determined that Lessor is not the owner of the entire tract above described, then and thereupon Lessor shall receive a proportional amount in accordance with the rentals and royalties for any fraction of the above premises so owned.

Payment of all moneys due on this lease may be made, by cash or check, to..; by deposit to ....credit in The.......................... Bank of..; or by check made payable to..............................order and mailed to..........................at ....

Lessor agrees that Lessee is to have the privilege of using sufficient oil, gas, or water, for fuel, in operating premises and the right at any time to remove any machinery or fixtures placed on said premises and further, upon the payment to the Lessor of one dollar and all amounts due hereunder, said Lessee shall have the right to surrender this lease or any portion thereof by written notice to Lessor describing the portion of the above tract that it elects to surrender or by returning to Lessor the lease with the endorsement of surrender thereon or recording the surrender of this lease on the margin of the record hereof, either of which shall be a full and legal surrender of this lease to all of said tract or such portion thereof as said surrender shall indicate and a cancellation of all liabilities under same of each and all parties hereto, to the extent indicated on said surrender, and the acreage rental hereinbefore set forth shall be reduced in proportion to the acreage surrendered.

All covenants and conditions between the parties hereto shall extend to their heirs, executors, successors and assigns and the Lessor hereby warrants and agrees to defend the title to the lands herein described; Lessor further agrees that the Lessee shall have the right at any time to redeem for Lessor, or otherwise acquire by payment, any mortgages or any other liens upon the above described lands which in any manner affect the Lessee's interest therein in the event of default of payment by Lessor and be subrogated in full to all the rights of the holder thereof the same as if Lessee were the original owner of said mortgage or lien.

IN WITNESS WHEREOF, the parties hereto have hereunto set their hands and seals.

Signed and Acknowledged in the Presence of:

....	........................(Seal.)
....	........................(Seal.)
....	........................(Seal.)
....	........................(Seal.)
	THE..........COMPANY,
	By...........................

cases a geological knowledge that may be obtained cannot be over-estimated. It may be the saving of large sums, and the bidder equipped with such information is in better shape than is the man whose system employs no intelligent methods. If one is under the influence of information obtained from "divining rods" or "peach limb" his methods are absolutely worthless, he may save himself the expense of obtaining such information, and a handful of mud thrown upon a map will indicate a desirable location with just as much accuracy and may be obtained at less expense.

The various methods of obtaining oil or gas properties may be roughly divided into different classes: thus it is possible to buy the property outright; the value of such transaction is that the payment of royalty and rental is avoided, as well as payment for damages that may be caused to the property or crops on it. The necessary tankage is reduced if many producing properties are owned by the producer, as the collecting of oil may be made at one place.

Another possibility is the buying of the mineral rights under a property, which has the advantage of either leasing the rights to others and receive the royalty from it, or in case the production is by the owner, no royalty will be paid by him, although he may be liable to damages caused by his operation.

The other and most common method is the leasing of property for drilling purposes. The methods and the forms used differ in various localities. The leases are generally made out on blank forms that may be obtained in the various localities. A lease form is shown herewith, a study of which will show the various possibilities that offer themselves in leasing.

After a lease is obtained the producer should have it abstracted, or in other words, determine the validity and the rights of the property owner as to his title to the land he is leasing, whether he has a clear title to it, or if others, such as heirs or partners, may also have an interest in the farm. In some cases (minors), it is necessary that a guardian is to be appointed to transact the business of the deed owner and to look after his interest. In all cases the lessor's signature should

show whether he is single or married, and if married his wife's signature should also be obtained and shown on the lease.

The lessor's signature should be "acknowledged" before a

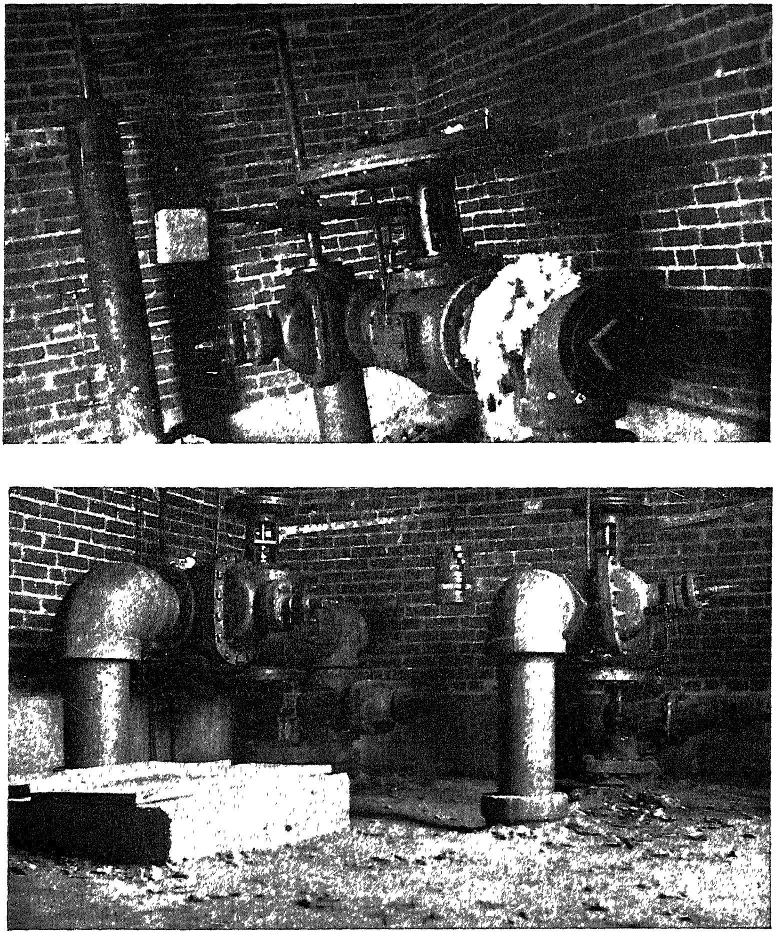


FIG. 127.—Medium and High Pressure Gas Regulators.

notary, and the lease be recorded at the proper court house. Leases generally carry a surrender clause, which is to the effect that if the lessee does not drill the well, or continue the payment of the stipulated sum per acre per year, he is to surrender his

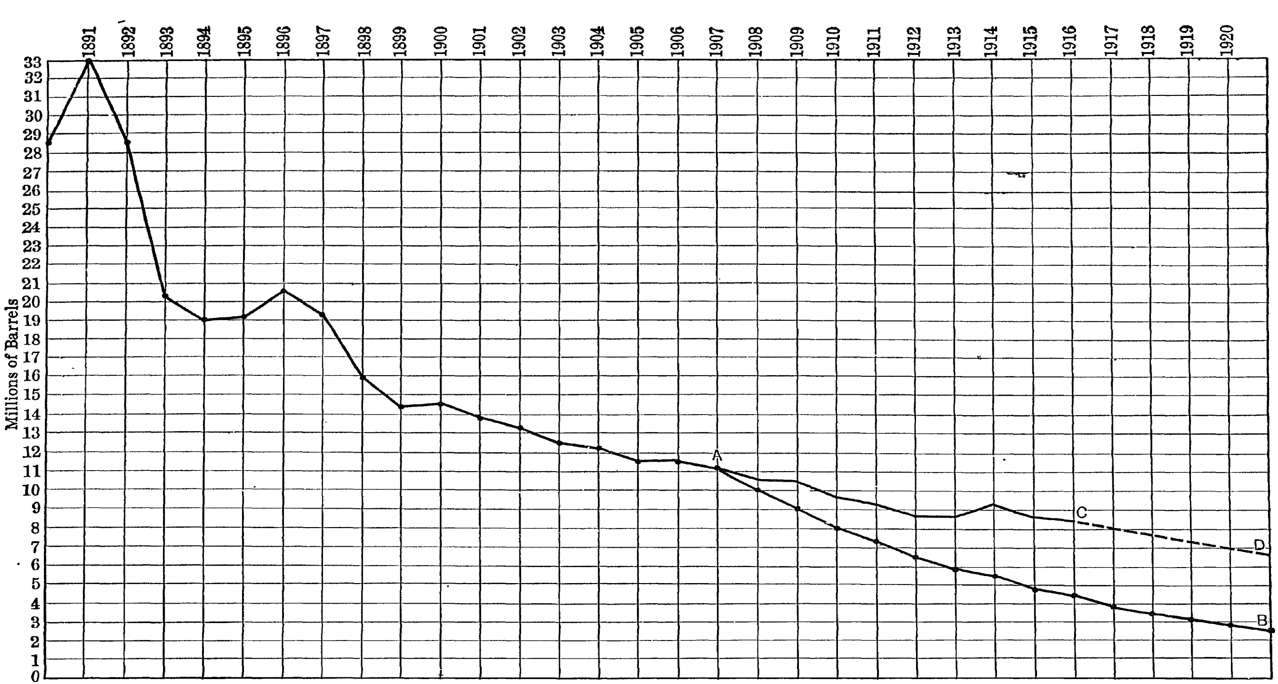


FIG. 128.—Decline Curve, showing the decline in production of the New York and Pennsylvania Oil Fields and its probable rate in the future. Similar curves may be constructed for individual pools or wells. The above curve was constructed from data obtained until 1907, line *AB* was then drawn, indicating the possible future production until 1921. The writer has constructed line *AC* from data obtained during 1907 and 1916, showing the difference between the calculated estimate and the actual production during that time, *CD* is the probable future production until 1921 indicated by data obtained until 1916.

rights in that lease and return same to the lessor. In other words it is a written agreement showing that the lessee has relinquished his rights in the lease and has returned same to the landowner.

The royalty of the landowner may be bought and sold as desired. It is sometimes circulated that the risk attached to buying royalties are less than drilling for the well; however, this is not the case, as if the royalty is bought before the well is drilled it is of value only should the well be actually drilled and proves to be a good one, but if the royalty is bought after the well is drilled and production obtained the price of such royalties will be in keeping with its value. Many such one-eighth royalties are bought by individuals, then split-up into many smaller portions and sold at rather high prices.

The producer comes in contact with the landowner quite often, as in the course of operation it may be necessary to lay pipe lines over various farms, in order that this may be done a right-of-way must first be bought at so much per rod. It may be necessary to install a gas pressure regulator (Fig. 127), or a meter house, in all cases agreements are to be reached with the land-owner. The producer is also liable for damages done to the farm and crops thereon, and in such cases the two or their representatives get together to agree on the value of the damaged property.

APPENDIX

TABLE V

GENERAL SECTION OF UNEXPOSED ROCKS OF THE CARNEGIE QUADRANGLE, PA.

(U. S. G. S. Bulletin 456)

System.	Formation.	Name Given by Drillers.	Geological Name.
Carboniferous.	Pottsville...	Gas sand....................	Probably equivalent to Homewood sandstone member.
		Salt or Forty-foot sand.......	Probably equivalent to Connoquenessing sandstone member.
	Pocono.....	Mountain or Big Injun sand...	Probably equivalent to Burgoon sandstone member.
		Squaw sand.	
		Papoose sand.	
		Bitter Rock sand.	
		Butler gas, Butler Thirty-foot, Gas, Salt, or Murrysville sand. (Probably = Berea sand.)	
		Hundred-foot or Gantz and Fifty-foot.	
Devonian(?).	Catskill(?)..	Nineveh Thirty-foot sand.	
		Snee (Blue Monday) sand, Stray-stray sand, and Bowlder sand.	
		Third Stray or Gordon Stray, or Campbell Run (?) sand.	
		Third or Gordon sand.	
		Fourth sand.	
		Fifth sand.	
Devonian.	Chemung(?)	Bayard or Sixth sand.	
		?	
		Elizabeth sand.	
		Warren first sand(?).	
		Warren second sand (?).	
	Portage (?)..		

Table VI

GENERALIZED SECTION OF ROCKS IN THE WOOSTER OIL AND GAS FIELD, OHIO

(U. S. G. S. Bulletin 621–H)

System.	Formation.	Driller's Name.	Thickness in Feet.	Character.
Quaternary (Pleistocene).	Glacial drift.	Sand and gravel.	0–75	Bowlder clay, sand, pebbles, shale fragments and bowlders.
Carboniferous (Mississippian).	Cuyahoga formation.	(?)	500–650	Dark shales with interbedded sandstones and sandy shales.
	Sunbury shale.			Black argillaceous bituminous shale.
	Berea sandstone.	Berea grit.	30–60	Medium-grained gray to buff-colored sandstone.
Devonian or Carboniferous.	Bedford shale.	Ohio shale.	1300–1370	Black and brown carbonaceous shale containing numerous "iron stone" concretions.
	Ohio shale group. Cleveland shale.			
	Ohio shale group. Chagrin formation			
Devonian	Ohio shale group. Huron shale.			
	Olentangy shale.			
	Delaware limestone.	Big lime.*	1030–1080	Brown, blue, and gray limestones, containing a few thin sandstone and shale beds in the lower portion.
	Columbus limestone.			
Unconformity —	Monroe formation.			
	Niagara limestone.			
Silurian.	"Clinton" formation.	Little lime probably belongs here	120–150†	Gray or red sandstone and dark shale, with interbedded limeston layers.
		Clinton sand.	0–30†	
	" Medina " shale.	Medina red rock.	0–40†	Red clay shale.

* This should not be confused with the Big lime of Pennsylvania, West Virginia, and Kentucky, which is of Carboniferous age.

† Figures added by writer.

TABLE VII

GENERALIZED SECTION OF FORMATIONS IN THE CORSICANA OIL AND GAS FIELD, TEXAS

(U. S. G. S. Bulletin 661–F)

System.	Series.	Group.	Formation.	Thickness (Feet).	Character.
Quaternary.	Recent.				Alluvial deposits along streams.
	Pleistocene.				Terrace deposits.
Tertiary.	Eocene.		Midway formation.	250–500	Micaceous sandy clays, fine argillaceous sands, and limestone concretions.
Cretaceous.	Gulf (Upper Cretaceous).		Navarro formation.*	1800–2000	Light to dark gray calcareous clay, sandy clay, and fine lenticular beds of sand.
			Taylor marl.		Massive calcareous clay marl, little or no sand, and glauconite.
			Austin chalk.	400–500	Gray to white chalky limestone containing some hard beds.
			Eagle Ford shale.	300–400	Light to dark colored shale or clay and thinly laminated impure limestone.
			Woodbine sand.	400–450	Sand, sandy lignitic clay, sandstone, ferruginous sand, and clay.
	Comanche (Lower Cretaceous).	Washita.	Denison formation.	150–200	Clay and limestone.
			Fort Worth limestone.	25–75	Alternating beds of limestone and marl.
			Preston formation.	50–100	Calcareous laminated clays and impure limestone.
		Fredericksburg.	Edwards limestone.	300–400	White chalky limestones, variously indurated, and in places fine arenaceous beds.
			Comanche Peak limestone.		
			Walnut clay.	100–200	Calcareous clays and impure marly and chalky limestones.
		Trinity.	Paluxy sand.	125–200	Fine-grained sand and lenticular beds of clay.
			Glen Rose limestone.	300–500	Impure limestone. marl, and calcareous shales.
			Travis Peak sand.	250±	Conglomerate, sand, sandstone, shales, and impure limestones.

* The formations below the Navarro formation crop out west of the Corsicana field and dip under it. The Upper Cretaceous formations have been penetrated by the drill in this field and are known from well records; the Lower Cretaceous formations have not been penetrated by the drill in this field but are known from outcrops and well records west of the field. The data relating to the Lower Cretaceous are taken largely from a report by R. T. Hill (Geography and geology of the Black and Grand prairies, Tex.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, 1901).

TABLE VIII

SECTION OF FORMATIONS INVOLVED IN THE HATCHETIGBEE ANTICLINE, ALABAMA

(U. S. G. S. Bulletin 661–H)

System.	Series.	Group.	Formation.	Thickness in Feet.	Lithologic Character.
Quaternary.	Recent.		Alluvium.		Clay, silt, and sand along present streams.
	Pleistocene.		Alluvial terrace deposits.		Sand, gravel, and clay.
Tertiary.	Pliocene.		Citronelle formation.	0–100	Terrace sand and gravel.
	Oligocene.		Catahoula sandstone.	0–200	Light-gray sands, sandstones, and greenish-gray siliceous clays.
			"Coral lime-stone."	0–90	Limestone, hard and soft beds alternating, composed in part largely of corals.
		Vicksburg.	Marianna limestone.	0–90	Limestone, light gray to white, soft, chalky ("chimney rock") below, and hard, semicrystalline, cavernous, (Glendon limestone member, locally termed "horsebone") above.
			Red Bluff clay.	20–40	Glauconitic clay, marl, and marly limestone below and plastic greenish-gray clay and gypsiferous and in places carbonaceous clay above.
	Eocene.		Jackson formation.	80–115	Clay, sand, and indurated marl; plastic bluish-green clay at base, followed above by medium fine-grained sand, light-gray indurated marl, and plastic gray or greenish-gray clay at top.
		Claiborne.	Gosport sand.	40–200	Greensand and indurated glauconitic sandy marl and subordinate beds of glauconitic clay; replete with shells, especially the greensand.

TABLE VIII—*Continued*

System.	Series.	Group.	Formation.	Thickness in Feet.	Lithologic Character.
Tertiary.	Eocene.	Claiborne.	Lisbon formation.	40–200	Sand, clay, indurated marl, sandstones, and oyster beds; the sands are highly glauconitic and weather red. Almost entirely marine; in large part highly fossiliferous.
			Tallahatta buhrstone.	20–200	Claystone, sandstone, and argillaceous sandstone, light gray, greenish gray, or green, glauconitic, medium to thin bedded noncalcareous, highly siliceous, sparingly fossiliferous except in few beds.
		Wilcox.	Hatchetigbee formation.	200–300	Sand, laminated sand and clay, sandy clay, and plastic clay; these materials are light to dark gray or greenish gray when fresh, but weather to yellow or brown. A large part of the formation is lignitic, but it also contains numerous beds of marine shells.
			Bashi formation.	80–125	Greensand marl, sandy clay, and beds of lignite; in upper part this formation contains marine shells in abundance and in lower part numerous thin beds of lignite.
			Tuscahoma formation.	140–200	Sandy clays, sands, and greensands, gray in color and containing several shell beds.
			Nanafalia formation.	200–250	Clays and sandy clays, indurated and in part glauconitic, followed below by light-gray sands, greensands, and sandy clays; lignite is present at base of formation in some places, and marine shells are abundant in upper part.
		Midway.	Naneola formation.	150–200	Clay and sand beds, alternating; sands are gray and glauconitic and clays are dark gray to black and sandy; marine shells in lower part.

TABLE VIII—*Continued*

System.	Series.	Group.	Formation.	Thickness in Feet.	Lithologic Character.
Tertiary.	Eocene.	Midway.	Sucarnochee clay.	100-200	Clay, dark brown to black, hard and dense; shells abundant at some places and absent at others.
			Clayton limestone.	0-25	Limestone, chalky limestone, and hard limestone beds, white to light gray in color, in part clayey and in part sandy. This limestone is absent in some parts of southwestern Alabama.
Cretaceous.	Upper Cretaceous.		Ripley formation.	0-150	Sands, clays, marls, and impure limestones; absent in part of southwestern Alabama, where it merges into Selma chalk; entirely of marine origin.
			Selma chalk.	900-1000	Chalk, chalky limestone, and thin beds of pure hard limestone; the chalk is grayish white or bluish gray to dark gray, in part clayey and in part sandy.
			Eutaw formation.	400-500	Sands, laminated sand and clay, and thin beds of lignitic clays; sands are marine, in part massive and in part cross-bedded.
			Tuscaloosa formation.	300-1000	Sands, clays, and gravels, irregularly bedded, nonmarine; contain carbonaceous and lignitic beds in upper part and gravel in the basal part; sands and clays are gray to dark gray or green.

Table IX

PARTIAL GENERALIZED SECTION OF THE AUSTIN, TEX., QUADRANGLE *

System.	Series or Group.	Formation.	Kind of Material.	Approximate Thickness.
Quaternary.			Silt, sand, and gravel.	Feet. 0–90
Tertiary.	Neocene.	Uvalde.	Gravel.	0–70
	Eocene.	Lytton.	Clay, sand, and sandstone.	300 +
Cretaceous (Upper).	Montana.	Webberville.	Black, slaty, bituminous clays with occasional layers. Contains green-sand particles. Slightly impregnated oil and gas. The oil-bearing formation of the Corsicana field.	400 ±
		Taylor.	Blue, unctuous marly clay ("joint clay") weathering into yellow subsoil and black soil.	540±
	Colorado.	Austin.	White chalk, with conchoidal fracture. Marly in upper portion.	410±
		Eagle Ford.	Blue clay and flaggy limestone. Oil traces.	30±

* Hill, R. T., and Vaughan, T. W., Austin folio (No. 76), Geol. Atlas, U. S., U. S. Geol. Survey, 1902.

TABLE X

WYOMING GEOLOGICAL COLUMN

CENTRAL STATE FIELDS

(From Oil and Gas Journal, Tulsa, Okla.)

Eras.	Ages.	Periods.	Epochs.	Local Application.
Cenozoic.	Tertiary.	Eocene.	Coryphodon.	White River formation.
Mesozoic.	Cretaceous.	Laramie.	Montana.	Fox Hills formation.
		Upper Cretaceous.	Pierre.	Shelly sands and shales with Teapot, Parkman and Shannon sands, Mesaverde and Steel shales.
		Pteranodon beds.	Colorado.	Niobrara and Carlile shales, Frontier formations and the three Wall Creek sands, also mowry and Thermopolis shales.
		Lower Cretaceous.	Dakota.	Dakota sands, Cloverly shales, Comanche shales.
	Jurassic.	Atlantosaurus beds.	Morrison.	Morrison shales and sands, Sundance sands and limes.
	Triassic.	Connecticut	Chugwater.	Chugwater dark shales with some stray sands and bastard limes, also iron ore veins.
Paleozoic.	Carboniferous.	Permian.	Tensleep.	Two Embar sands and Tensleep with thin coals and iron ore and limes.
	Sub-Carboniferous		Amsden.	Amsden shales and sands, Ach Louie sand, iron ore veins, Madison lime.
	Devonian, Silurian, Cambrian.	Corniferous and others		Several massive limes overlying quartzite and shale beds, mica schist granites, asbestos veins.

TABLE XI

ROCK FORMATIONS IN SALT CREEK OIL FIELD, WYO.

(U. S. G. S. Bulletin 670)

System.	Series.	Group.	Formations and Members as Classified in the Writer's Former Report on the Field.	Formations and Members Recognized in this Report.	Character.	Thickness in Feet.
Tertiary.	Eocene.		Fort Union formation.	Wasatch formation.	Yellow sandstone, gray shale and coal.	2400
Tertiary.	Eocene.		Fort Union formation.	Fort Union formation.	Fine-grained bluish-white sandstone and gray shale.	2000
Tertiary(?)	(?)		Lance formation.	Lance formation.	Concretionary buff sandstone and shale bearing *Triceratops* remains.	3200
Cretaceous.	Upper Cretaceous.	Montana.	Fox Hills sandstone.	Lewis shale with thick sandstone at top and another sandstone in middle.	Sandstone, white to brown, and gray shale.	1400
Cretaceous.	Upper Cretaceous.	Montana.	Pierre formation.	Mesaverde formation, including Parkman and Teapot sandstone members.	Shale, sandstone, thin coal beds.	845
			Pierre formation. Parkman sandstone member.			
Cretaceous.	Upper Cretaceous.	Montana.	Pierre formation. Shannon sandstone lentil.	Steele shale, including Shannon sandstone member.	Buff sandstone and gray shale.	2275
Cretaceous.	Upper Cretaceous.	Colorado.	Niobrara shale.	Niobrara shale.	Light-colored shale, in parts somewhat arenaceous.	735
Cretaceous.	Upper Cretaceous.	Colorado.	Benton shale.	Benton shale.	Dark shale.	220
Cretaceous.	Upper Cretaceous.	Colorado.	Benton shale. Wall Creek sandstone lentil.	Benton shale. Wall Creek sandstone member and lower sands with interbedded shale.	Buff to white sandstone and gray shale.	685
Cretaceous.	Upper Cretaceous.	Colorado.	Benton shale.	Benton shale.	Dark shale.	250
Cretaceous.	Upper Cretaceous.	Colorado.	Benton shale. Mowry shale member.	Benton shale. Mowry shale member.	Firm slaty shale, usually forming escarpment. Weathers light gray and bears numerous fish scales.	280
Cretaceous.	Upper Cretaceous.	Colorado.	Benton shale.	Benton shale.	Dark shale.	205
Cretaceous.	Lower Cretaceous.		Benton shale.	Cloverly formation.	Thin sandstone and dark shale.	150
Cretaceous.	Lower Cretaceous.		Dakota (?) sandstone.	Cloverly formation.	Conglomerate.	
Cretaceous(?)	(?)		Morrison formation.	Morrison formation.	Variegated shale with several sandstone beds.	250
Jurassic.	Upper Jurassic.		- - - -	Sundance formation	Shale, limestone, and sandstone.	150

Table XII

GENERAL SECTION OF THE ROCKS OF THE BOWDOIN DOME, MONTANA

(U. S. G. S. Bulletin 661-E.)

System.	Series.	Group.	Formation.	Thickness (Feet.)	Character.
Quaternary.	Recent.			.	Silts in the flood plains of streams.
	Pleistocene.				Scattered crystalline bowlders; glacial moraines.
					Silt, sand, and gravel deposited along the old channels of the Missouri, Musselshell, and other streams before the end of the glacial epoch.
					Gravel interstratified with yellowish silt at an altitude of 300 feet above Milk River valley. May possibly be late Pliocene.
Cretaceous.	Upper Cretaceous.	Montana.	Bearpaw shale.	800–1000	Dark gray shale; forms gumbo soil.
			Judith River formation.	400	Light-gray clay and irregular beds of gray and brown sandstone.
			Clagget shale	750	Dark-gray shale; forms gumbo soil. About 500 feet exposed in Bowdoin dome.
			Eagle (?) sandstone.	100±	Light-gray sandstone; forms a low ridge; contains limestone concretions in its upper part.
		Colorado.		875	Bluish-gray to black shale; contains limestone concretions and marine fossils.
				60±	Light-gray sandstone, capped by a thin limestone containing numerous gastropods.
				485±	Bluish-gray to black shale.
			Mowry shale.	100±	Platy shale or sandstone, which is in places dark-colored but weathers white; contains numerous fish scales; yields traces of oil by distillation.
	Lower Cretaceous.		Kootenai (?) formation.	825±	Mainly shale but includes some poorly defined sandstone. In lower part red and purple shales were noted. A bed of fresh-water sandstone and carbonaceous shale with fragments of woody stems near the base.
Jurassic.	Upper Jurassic		Ellis formation.	200±	Massive white and yellow sandstone.
				200±	Shale containing *Belemnites*.
Carboniferous.	Mississippian.		Madison limestone.		Massive limestone.

Table XIII

GENERAL SECTION OF ROCKS OUTCROPPING IN THE GREEN RIVER FIELD, UTAH

(U. S. G. S. Bulletin 541-D.)

System.	Formation.	Member.	Description of Strata.	Thickness (Feet).	Economic Value.
Cretaceous.	Mancos shale.		Yellow to bluish drab sandy shale; the upper part is very sandy and contains beds and lenses of sandstone; the middle and lower parts are mainly shale.	About 2500 (after Richardson).	
		Ferron sandstone member.	This sandstone contains in places concretions which are fossiliferous. It forms a hogback through the field.	50–100	Possibly this sandstone is a reservoir for the gas that has been obtained in some of the wells.
			Bluish drab sandy shale; sandy material is most plentiful near the base and top of this part of the formation.	About 400.	
	Dakota sandstone.		Yellowish-gray sandstone with thin beds of shale alternating. Sandstones, coarse, soft, and in places very conglomeratic.	0–40	Contains a little coal in places, but none was observed in this field.
			Unconformity.		
Jurassic (?).	McElmo formation.		Gray conglomerate, variegated sandy shale, and clay, and a few feet of limestone about 175 feet from the top. Some of the sandstone is quartzitic.	325–350	A few lenses of sandstone contain pockets of gas. Other lenses are partly saturated with petroleum.
		Salt Wash sandstone member.	Gray conglomeratic sandstone which outcrops in cliffs. The sandstone in places is lenticular, soft, and friable.	150–175	Water-bearing in places. Probably contains a little gas and a trace of oil.
			Red sandstone, thin-bedded above and massive below.	About 700.	Gypsum and manganese in the upper part.
Jurassic.	La Plata sandstone.		Very cross-bedded, coarse, gray sandstone.	Estimated 700.	Water-bearing in many places.

TABLE XIV

HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS

Minutes.	0°.		1°.		2°.		3°.	
	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.
0	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23
2	100.00	0.06	99.97	1.80	99.87	3.55	99.72	5.28
4	100.00	0.12	99.97	1.86	99.87	3.60	99.71	5.34
6	100.00	0.17	99.96	1.92	99.87	3.66	99.71	5.40
8	100.00	0.23	99.96	1.98	99.86	3.72	99.70	5.46
10	100.00	0.29	99.96	2.04	99.86	3.78	99.69	5.52
12	100.00	0.35	99.96	2.09	99.85	3.84	99.69	5.57
14	100.00	0.41	99.95	2.15	99.85	3.90	99.68	5.63
16	100.00	0.47	99.95	2.21	99.84	3.95	99.68	5.69
18	100.00	0.52	99.95	2.27	99.84	4.01	99.67	5.75
20	100.00	0.58	99.95	2.33	99.83	4.07	99.66	5.80
22	100.00	0.64	99.94	2.38	99.83	4.13	99.66	5.86
24	100.00	0.70	99.94	2.44	99.82	4.18	99.65	5.92
26	99.99	0.76	99.94	2.50	99.82	4.24	99.64	5.98
28	99.99	0.81	99.93	2.56	99.81	4.30	99.63	6.04
30	99.99	0.87	99.93	2.62	99.81	4.36	99.63	6.09
32	99.99	0.93	99.93	2.67	99.80	4.42	99.62	6.15
34	99.99	0.99	99.93	2.73	99.80	4.48	99.62	6.21
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61
50	99.98	1.45	99.90	3.20	99.76	4.94	99.56	6.67
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	9.90
60	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96
$c=0.75$	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05
$c=1.00$	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06
$c=1.25$	1.25	0.02	1.25	0.03	1.25	0.05	1.25	0 08

TABLE XIV—*Continued*

Minutes.	4°.		5°.		6°.		7°.	
	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.
0	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10
2	99.51	7.02	99.23	8.74	98.90	10.45	98.50	12.15
4	99.50	7.07	99.22	8.80	98.88	10.51	98.48	12.21
6	99.49	7.13	99.21	8.85	98.87	10.57	98.47	12.26
8	99.48	7.19	99.20	8.91	98.86	10.62	98.46	12.32
10	99.47	7.25	99.19	8.97	98.85	10.68	98.44	12.38
12	99.46	7.30	99.18	9.03	98.83	10.74	98.43	12.43
14	99.46	7.36	99.17	9.08	98.82	10.79	98.41	12.49
16	99.45	7.42	99.16	9.14	98.81	10.85	98.40	12.55
18	99.44	7.48	99.15	9.20	98.80	10.91	98.39	12.60
20	99.43	7.53	99.14	9.25	98.78	10.96	98.37	12.66
22	99.42	7.59	99.13	9.31	98.77	11.02	98.36	12.72
24	99.41	7.65	99.11	9.37	98.76	11.08	98.34	12.77
26	99.40	7.71	99.10	9.43	98.74	11.13	98.33	12.83
28	99.39	7.76	99.09	9.48	98.73	11.19	98.31	12.88
30	99.38	7.82	99.08	9.54	98.72	11.25	98.29	12.94
32	99.38	7.88	99.07	9.60	98.71	11.30	98.28	13.00
34	99.37	7.94	99.06	9.65	98.69	11.36	98.27	13.05
36	99.36	7.99	99.05	9.71	98.68	11.42	98.25	13.11
38	99.35	8.05	99.04	9.77	98.67	11.47	98.24	13.17
40	99.34	8.11	99.03	9.83	98.65	11.53	98.22	13.22
42	99.33	8.17	99.01	9.88	98.64	11.59	98.20	13.28
44	99.32	8.22	99.00	9.94	98.63	11.64	98.19	13.33
46	99.31	8.28	98.99	10.00	98.61	11.70	98.17	13.39
48	99.30	8.34	98.98	10.05	98.60	11.76	98.16	13.45
50	99.29	8.40	98.97	10.11	98.58	11.81	98.14	13.50
52	99.28	8.45	98.96	10.17	98.57	11.87	98.13	13.56
54	99.27	8.51	98.94	10.22	98.56	11.93	98.11	13.61
56	99.26	8.57	98.93	10.28	98.54	11.98	98.10	13.67
58	99.25	8.63	98.92	10.34	98.53	12.04	98.08	13.73
60	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78
$c=0.75$	0.75	0.06	0.75	0.07	0.75	0.08	0.74	0.10
$c=1.00$	1.00	0.08	0.99	0.09	0.99	0.11	0.99	0.13
$c=1.25$	1.25	0.10	1.24	0.11	1.24	0.14	1.24	0.16

TABLE XIV—*Continued*

Minutes.	8°.		9°.		10°.		11°.	
	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.
0	98.06	13.78	97.55	15.45	96.98	17.10	96.36	18.73
2	98.05	13.84	97.53	15.51	96.96	17.16	96.34	18.78
4	98.03	13.89	97.52	15.56	96.94	17.21	96.32	18.84
6	98.01	13.95	97.50	15.62	96.92	17.26	96.29	18.89
8	98.00	14.01	97.48	15.67	96.90	17.32	96.27	18.95
10	97.98	14.06	97.46	15.73	96.88	17.37	96.25	19.00
12	97.97	14.12	97.44	15.78	96.86	17.43	96.23	19.05
14	97.95	14.17	97.43	15.84	96.84	17.48	96.21	19.11
16	97.93	14.23	97.41	15.89	96.82	17.54	96.18	19.16
18	97.92	14.28	97.39	15.95	96.80	17.59	96.16	19.21
20	97.90	14.34	97.37	16.00	96.78	17.65	96.14	19.27
22	97.88	14.40	97.35	16.06	96.76	17.70	96.12	19.32
24	97.87	14.45	97.33	16.11	96.74	17.76	96.09	19.38
26	97.85	14.51	97.31	16.17	96.72	17.81	96.07	19.43
28	97.83	14.56	97.29	16.22	96.70	17.86	96.05	19.48
30	97.82	14.62	97.28	16.28	96.68	17.92	96.03	19.54
32	97.80	14.67	97.26	16.33	96.66	17.97	96.00	19.59
34	97.78	14.73	97.24	16.39	96.64	18.03	95.98	19.64
36	97.76	14.79	97.22	16.44	96.62	18.08	95.96	19.70
38	97.75	14.84	97.20	16.50	96.60	18.14	95.93	19.75
40	97.73	14.90	97.18	16.55	96.57	18.19	95.91	19.80
42	97.71	14.95	97.16	16.61	96.55	18.24	95.89	19.86
44	97.69	15.01	97.14	16.66	96.53	18.30	95.86	19.91
46	97.68	15.06	97.12	16.72	96.51	18.35	95.84	19.96
48	97.66	15.12	97.10	16.77	96.49	18.41	95.82	20.02
50	97.64	15.17	97.08	16.83	96.47	18.46	95.79	20.07
52	97.62	15.23	97.06	16.88	96.45	18.51	95.77	20.12
54	97.61	15.28	97.04	16.94	96.42	18.57	95.75	20.18
56	97.59	15.34	97.02	16.99	96.40	18.62	95.72	20.23
58	97.57	15.40	97.00	17.05	96.38	18.68	95.70	20.28
60	97.55	15.45	96.98	17.10	96.36	18.73	95.68	20.34
c=0.75	0.74	0.11	0.74	0.12	0.74	0.14	0.73	0.15
c=1.00	0.99	0.15	0.99	0.16	0.98	0.18	0.98	0.20
c=1.25	1.23	0.18	1.23	0.21	1.23	0.23	1.22	0.25

TABLE XIV—*Continued*

Minutes.	12°.		13°.		14°.		15°.	
	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.
0	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00
2	95.65	20.39	94.91	21.97	94.12	23.52	93.27	25.05
4	95.63	20.44	94.89	22.02	94.09	23.58	93.24	25.10
6	95.61	20.50	94.86	22.08	94.07	23.63	93.21	25.15
8	95.58	20.55	94.84	22.13	94.04	23.68	93.18	25.20
10	95.56	20.60	94.81	22.18	94.01	23.73	93.16	25.25
12	95.53	20.66	94.79	22.23	93.98	23.78	93.13	25.30
14	95.51	20.71	94.76	22.28	93.95	23.83	93.10	25.35
16	95.49	20.76	94.73	22.34	93.93	23.88	93.07	25.40
18	95.46	20.81	94.71	22.39	93.90	23.93	93.04	25.45
20	95.44	20.87	94.68	22.44	93.87	23.99	93.01	25.50
22	95.41	20.92	94.66	22.49	93.84	24.04	92.98	25.55
24	95.39	20.97	94.63	22.54	93.81	24.09	92.95	25.60
26	95.36	21.03	94.60	22.60	93.79	24.14	92.92	25.65
28	95.34	21.08	94.58	22.65	93.76	24.19	92.89	25.70
30	95.32	21.13	94.55	22.70	93.73	24.24	92.86	25.75
32	95.29	21.18	94.52	22.75	93.70	24.29	92.83	25.80
34	95.27	21.24	94.50	22.80	93.67	24.34	92.80	25.85
36	95.24	21.29	94.47	22.85	93.65	24.39	92.77	25.90
38	95.22	21.34	94.44	22.91	93.62	24.44	92.74	25.95
40	95.19	21.39	94.42	22.96	93.59	24.49	92.71	26.00
42	95.17	21.45	94.39	23.01	93.56	24.55	92.68	26.05
44	95.14	21.50	94.36	23.06	93.53	24.60	92.65	26.10
46	95.12	21.55	94.34	23.11	93.50	24.65	92.62	26.15
48	95.09	21.60	94.31	23.16	93.47	24.70	92.59	26.20
50	95.07	21.66	94.28	23.22	93.45	24.75	92.56	26.25
52	95.04	21.71	94.26	23.27	93.42	24.80	92.53	26.30
54	95.02	21.76	94.23	23.32	93.39	24.85	92.49	26.35
56	94.99	21.81	94.20	23.37	93.36	24.90	92.46	26.40
58	94.97	21.87	94.17	23.42	93.33	24.95	92.43	26.45
60	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50
$c=1.75$	0.73	0.16	0.73	0.17	0.73	0.19	0.72	0.20
$c=1.00$	0.98	0.22	0.97	0.23	0.97	0.25	0.96	0.27
$c=1.25$	1.22	0.27	1.21	0.29	1.21	0.31	1.20	0.34

TABLE XIV—*Continued*

Minutes.	16°.		17°.		18°.		19°.	
	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.
0	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78
2	92.37	26.55	91.42	28.01	90.42	29.44	89.36	30.83
4	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87
6	92.31	26.64	91.36	28.10	90.35	29.53	89.29	30.92
8	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97
10	92.25	26.74	91.29	28.20	90.28	29.62	89.22	31.01
12	92.22	26.79	91.26	28.25	90.24	29.67	89.18	31.06
14	92.19	26.84	91.22	28.30	90.21	29.72	89.15	31.10
16	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15
18	92.12	26.94	91.16	28.39	90.14	29.81	89.08	31.19
20	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24
22	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28
24	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33
26	92.00	27.13	91.02	28.58	90.00	30.00	88.93	31.38
28	91.97	27.18	90.99	28.63	89.97	30.04	88.89	31.42
30	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47
32	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.51
34	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56
36	91.84	27.38	90.86	28.82	89.83	30.23	88.75	31.60
38	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65
40	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31.69
42	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74
44	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78
46	91.68	27.62	90.69	29.06	89.65	30.46	88.56	31.83
48	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87
50	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92
52	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96
54	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01
56	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05
58	91.48	27.91	90.48	29.34	89.44	30.74	88.34	32.09
60	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14
$c=0.75$	0.72	0.21	0.72	0.23	0.71	0.24	0.71	0.25
$c=1.00$	0.86	0.28	0.95	0.30	0.95	0.32	0.94	0.33
$c=1.25$	1.20	0.35	1.19	0.38	1.19	0.40	1.18	0.42

TABLE XIV—*Continued*

Minutes.	20°.		21°.		22°.		23°.	
	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.
0	88.30	32.14	87.16	33.46	85.97	34.73	84.73	35.97
2	88.26	32.18	87.12	33.50	85.93	34.77	84.69	36.01
4	88.23	32.23	87.08	33.54	85.89	34.82	84.65	36.05
6	88.19	32.27	87.04	33.59	85.85	34.86	84.61	36.09
8	88.15	32.32	87.00	33.63	85.80	34.90	84.57	36.13
10	88.11	32.36	86.96	33.67	85.76	34.94	84.52	36.17
12	88.08	32.41	86.92	33.72	85.72	34.98	84.48	36.21
14	88.04	32.45	86.88	33.76	85.68	35.02	84.44	36.25
16	88.00	32.49	86.84	33.80	85.64	35.07	84.40	36.29
18	87.96	32.54	86.80	33.84	85.60	35.11	84.35	36.33
20	87.93	32.58	86.77	33.89	85.56	35.15	84.31	36.37
22	87.89	32.63	86.73	33.93	85.52	35.19	84.27	36.41
24	87.85	32.67	86.69	33.97	85.48	35.23	84.23	36.45
26	87.81	32.72	86.65	34.01	85.44	35.27	84.18	36.49
28	87.77	32.76	86.61	34.06	85.40	35.31	84.14	36.53
30	87.74	32.80	86.57	34.10	85.36	35.36	84.10	36.57
32	87.70	32.85	86.53	34.14	85.31	35.40	84.06	36.61
34	87.66	32.89	86.49	34.18	85.27	35.44	84.01	36.65
36	87.62	32.93	86.45	34.23	85.23	35.48	83.97	36.69
38	87.58	32.98	86.41	34.27	85.19	35.52	83.93	36.73
40	87.54	33.02	86.37	34.31	85.15	35.56	83.89	36.77
42	87.51	33.07	86.33	34.35	85.11	35.60	83.84	36.80
44	87.47	33.11	86.29	34.40	85.07	35.64	83.80	36.84
46	87.43	33.15	86.25	34.44	85.02	35.68	83.76	36.88
48	87.39	33.20	86.21	34.48	84.98	35.72	83.72	36.92
50	87.35	33.24	86.17	34.52	84.94	35.76	83.67	36.96
52	87.31	33.28	86.13	34.57	84.90	35.80	83.63	37.00
54	87.27	33.33	86.09	34.61	84.86	35.85	83.59	37.04
56	87.24	33.37	86.05	34.65	84.82	35.89	83.54	37.08
58	87.20	33.41	86.01	34.69	84.77	35.93	83.50	37.12
60	87.16	33.46	85.97	34.73	84.73	35.97	83.46	37.16
$c=0.75$	0.70	0.26	0.70	0.27	0.69	0.29	0.69	0.30
$c=1.00$	0.94	0.35	0.93	0.37	0.92	0.38	0.92	0.40
$c=1.25$	1.17	0.44	1.16	0.46	1.15	0.48	1.15	0.50

TABLE XIV—*Continued*

Minutes.	24°.		25°.		26°.		27°.	
	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.
0	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45
2	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49
4	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52
6	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40.55
8	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59
10	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62
12	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66
14	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69
16	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72
18	83.07	37.51	81.74	38.64	80.37	39.72	78.96	40.76
20	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79
22	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82
24	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86
26	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89
28	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92
30	82.80	37.74	81.47	38.86	80.09	39.93	78.68	40.96
32	82.76	37.77	81.42	38.89	80.04	39.97	78.63	40.99
34	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02
36	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06
38	82.63	37.89	81.28	39.00	79.90	40.07	78.49	41.09
40	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12
42	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16
44	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19
46	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22
48	82.41	38.08	81.06	39.18	79.67	40.24	78.25	41.26
50	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29
52	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32
54	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35
56	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39
58	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42
60	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45
c=0.75	0.68	0.31	0.68	0.32	0.67	0.33	0.66	0.35
c=1.00	0.91	0.41	0.90	0.43	0.89	0.45	0.89	0.46
c=1.25	1.14	0.52	1.13	0.54	1.12	0.56	1.11	0.58

TABLE XIV—*Continued*

Minutes.	28°.		29°.		30°.	
	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.	Horizontal Distance.	Difference of Elevation.
0	77.96	41.45	76.50	42.40	75.00	43.30
2	77.91	41.48	76.45	42.43	74.95	43.33
4	77.86	41.52	76.40	42.46	74.90	43.36
6	77.81	41.55	76.35	42.49	74.85	43 39
8	77.77	41.58	76.30	42.53	74.80	43.42
10	77.72	41.61	76.25	42.56	74.75	43.45
12	77.67	41.65	76.20	42.59	74.70	43.47
14	77.62	41.68	76.15	42.62	74.65	43.50
16	77.57	41.71	76.10	42.65	74.60	43.53
18	77.52	41.74	76.05	42.68	74.55	43.56
20	77.48	41.77	76.00	42.71	74.49	43.59
22	77.42	41.81	75.95	42.74	74.44	43.62
24	77.38	41.84	75.90	42.77	74.39	43.65
26	77.33	41.87	75.85	42.80	74.34	43.67
28	77.28	41.90	75.80	42.83	74.29	43.70
30	77.23	41.93	75.75	42.86	74.24	43.73
32	77.18	41.97	75.70	42.89	74.19	43.76
34	77.13	42.00	75.65	42.92	74.14	43.79
36	77.09	42.03	75.60	42.95	74.09	43.82
38	77.04	42.06	75.55	42.98	74.04	43.84
40	76.99	42.09	75.50	43.01	73.99	43.87
42	76.94	42.12	75.45	43.04	73.93	43.90
44	76.89	42.15	75.40	43.07	73.88	43.93
46	76.84	42.19	75.35	43.10	73.83	43.95
48	76.79	42.22	75.30	43.13	73.78	43.98
50	76.74	42.25	75.25	43.16	73.73	44.01
52	76.69	42.28	75.20	43.18	73.68	44.04
54	76.64	42.31	75.15	43.21	73.63	44.07
56	76.59	42.34	75.10	43.24	73.58	44.09
58	76.55	42.37	75.05	43.27	73.52	44.12
60	76.50	42.40	75.00	43.30	73.47	44.15
$c=0.75$	0.66	0.36	0.65	0.37	0.65	0.38
$c=1.00$	0.88	0.48	0.87	0.49	0.86	0.51
$c=1.25$	1.10	0.60	1.09	0.62	1.08	0.64

Table XV

DEPTH OF STRATA BELOW A HORIZONTAL SURFACE AT A DISTANCE OF 100 FEET FROM THE OUTCROP, AND ALONG THE DIP, THE THICKNESS OF A BED HAVING AN OUTCROP 100 FEET WIDE

Dip, Degrees.	Depth.	Thickness.	Dip, Degrees.	Depth.	Thickness.
1	1.75	1.75	16	28.63	27.56
2	3.49	3.49	17	30.57	29.23
3	5.24	5.23	18	32.49	30.90
4	6.99	6.97	19	34.43	32.55
5	8.75	8.71	20	36.40	34.20
6	10.51	10.45	21	38.39	35.83
7	12.28	12.19	22	40.40	37.46
8	14.05	13.92	23	42.45	39.07
9	15.84	15.64	24	44.52	40.67
10	17.63	17.36	25	46.63	42.26
11	19.44	19.08	26	48.77	43.83
12	21.26	20.79	27	50.95	45.40
13	23.09	22.49	28	53.17	46.94
14	24.93	24.19	29	55.43	48.48
15	26.80	25.88	30	57.74	50.00

(Modified from Redwood and Eastlake.) (After Johnson and Huntley.)

Table XVI

"SHOOTING" TABLE

Capacities of Nitro-glycerin Shells

Diameter and Length of Twenty-quart Shells

Diameter, Inches.	In. to Qt.	Length. Ft.	In.
2	18¾	30	10⅝
2¼	14½	24	5½
2½	11¾	19	10¼
2¾	9¾	16	5½
3	8½	13	10⅜
3¼	7	11	10¼
3½	6	10	3
3¾	5¼	8	11⅝
4	4⅝	7	10⅞
4¼	4⅛	7	⅜
4½	3⅝	6	3⅝
4¾	3¼	5	8⅛
5	3	5	3
5¼	2⅖	4	7½
5½	....	4	4
5¾	....	4	
6	....	3	7
6¼	....	3	4½
6½	....	3	2
6¾	....	2	11½
7	....	2	9

AMOUNT OF FLUID DIFFERENT SIZES OF PIPE HOLD

Diameter.	Gals. per Ft.	Gals. per 100 Ft.	Barrels per 100 Ft.	Barrels per 2000 Ft.
2 inch........	.143	14.3	....	6.81
4 inch........	.652	65.2	1.55	31.05
5 inch........	1.02	102.0	2.43	48.57
6 inch........	1.46	146.0	3.47	69.524
6½ inch.......	1.72	172.0	4.10	81.9
8 inch........	2.61	261.0	6.21	124.29
10 inch........	4.08	408.0	9.71	194.29
13 inch........	6.89	689.0	16.40	328.01

TABLE XVII

INCHES AND FRACTIONS OF AN INCH IN DECIMALS OF A FOOT

	0	1	2	3	4	5	6	7	8	9	10	11	
$\frac{1}{16}$	.0052	.0885	.1719	.2552	.3385	.4219	.5052	.5885	.6719	.7552	.8385	.9219	$\frac{1}{16}$
$\frac{1}{8}$	.0104	.0938	.1771	.2604	.3438	.4271	.5104	.5938	.6771	.7604	.8438	.9271	$\frac{1}{8}$
$\frac{3}{16}$	.0156	.0990	.1823	.2656	.3490	.4323	.5156	.5990	.6823	.7656	.8490	.9323	$\frac{3}{16}$
$\frac{1}{4}$	.0208	.1042	.1875	.2708	.3542	.4375	.5208	.6042	.6875	.7708	.8542	.9375	$\frac{1}{4}$
$\frac{5}{16}$	.0260	.1094	.1927	.2760	.3594	.4427	.5260	.6094	.6927	.7760	.8594	.9427	$\frac{5}{16}$
$\frac{3}{8}$	.0313	.1146	.1979	.2813	.3646	.4479	.5313	.6146	.6979	.7813	.8646	.9479	$\frac{3}{8}$
$\frac{7}{16}$	.0365	.1198	.2031	.2865	.3698	.4531	.5365	.6198	.7031	.7865	.8698	.9531	$\frac{7}{16}$
$\frac{1}{2}$	.0417	.1250	.2083	.2917	.3750	.4583	.5417	.6250	.7083	.7917	.8750	.9583	$\frac{1}{2}$
$\frac{9}{16}$	.0469	.1302	.2135	.2969	.3803	.4635	.5469	.6302	.7135	.7969	.8802	.9635	$\frac{9}{16}$
$\frac{5}{8}$	.0521	.1354	.2188	.3021	.3854	.4688	.5521	.6354	.7188	.8021	.8854	.9688	$\frac{5}{8}$
$\frac{11}{16}$	.0573	.1406	.2240	.3073	.3906	.4740	.5573	.6406	.7240	.8073	.8906	.9740	$\frac{11}{16}$
$\frac{3}{4}$	.0625	.1458	.2292	.3125	.3958	.4792	.5625	.6458	.7292	.8125	.8958	.9792	$\frac{3}{4}$
$\frac{13}{16}$	.0677	.1510	.2344	.3177	.4010	.4844	.5677	.6510	.7344	.8177	.9010	.9844	$\frac{13}{16}$
$\frac{7}{8}$	.0729	.1563	.2396	.3229	.4063	.4896	.5729	.6563	.7396	.8229	.9063	.9896	$\frac{7}{8}$
$\frac{15}{16}$	.0781	.1615	.2448	.3281	.4115	.4948	.5781	.6615	.7448	.8281	.9115	.9948	$\frac{15}{16}$
1	.0833	.1667	.2500	.3333	.4167	.5000	.5833	.6667	.7500	.8333	.9167	1.000	1
	0	1	2	3	4	5	6	7	8	9	10	11	

TABLE XVIII

RODS IN FEET AND INCHES

Rods	Ft.	In.	Rods	Ft.	In.	Rods	Ft.	In.	Rods	Ft.	In.	Rods	Ft.	In.
1	16	6	21	346	6	41	676	6	61	1006	6	81	1336	6
2	33	0	22	363	0	42	693	0	62	1023	0	82	1353	0
3	49	6	23	379	6	43	709	6	63	1039	6	83	1369	6
4	66	0	24	396	0	44	726	0	64	1056	0	84	1386	0
5	82	6	25	412	6	45	742	6	65	1072	6	85	1402	6
6	99	0	26	429	0	46	759	0	66	1089	0	86	1419	0
7	115	6	27	445	6	47	775	6	67	1105	6	87	1435	6
8	132	0	28	462	0	48	792	0	68	1122	0	88	1452	0
9	148	6	29	478	6	49	808	6	69	1138	6	89	1468	6
10	165	0	30	495	0	50	825	0	70	1155	0	90	1485	0
11	181	6	31	511	6	51	841	6	71	1171	6	91	1501	6
12	198	0	32	528	0	52	858	0	72	1188	0	92	1518	0
13	214	6	33	544	6	53	874	6	73	1204	6	93	1534	6
14	231	0	34	561	0	54	891	0	74	1221	0	94	1551	0
15	247	6	35	577	6	55	907	6	75	1237	6	95	1567	6
16	264	0	36	594	0	56	924	0	76	1254	0	96	1584	0
17	280	6	37	610	6	57	940	6	77	1270	6	97	1600	6
18	297	0	38	627	0	58	957	0	78	1287	0	98	1617	0
19	313	6	39	643	6	59	973	6	79	1303	6	99	1633	6
20	330	0	40	660	0	60	990	0	80	1320	0	100	1650	0

TABLE XIX

LINKS IN FEET AND INCHES

Links.	Ft.	In.	Links.	Ft.	In.	Links.	Ft.	In.	Links.	Ft.	In.	Links.	Ft.	In.
1	0	7.92	22	14	6.24	43	28	4.56	63	41	6.96	83	54	9.36
2	1	3.84	23	15	2.16	44	29	0.48	64	42	2.88	84	55	5.28
3	1	11.76	24	15	10.08	45	29	8.40	65	42	10.80	85	56	1.20
4	2	7.68	25	16	6.00	46	30	4.32	66	43	6.72	86	56	9.12
5	3	3.60	26	17	1.92	47	31	0.24	67	44	2.64	87	57	5.04
6	3	11.52	27	17	9.84	48	31	8.16	68	44	10.56	88	58	0.96
7	4	7.44	28	18	5.76	49	32	4.08	69	45	6.48	89	58	8.88
8	5	3.36	29	19	1.68	50	33	0.00	70	46	2.40	90	59	4.80
9	5	11.28	30	19	9.60	51	33	7.92	71	46	10.32	91	60	0.72
10	6	7.20	31	20	5.52	52	34	3.84	72	47	6.24	92	60	8.64
11	7	3.12	32	21	1.44	53	34	11.76	73	48	2.16	93	61	4.56
12	7	11.04	33	21	9.36	54	35	7.68	74	48	10.08	94	62	0.48
13	8	6.96	34	22	5.28	55	36	3.60	75	49	6.00	95	62	8.40
14	9	2.88	35	23	1.20	56	36	11.52	76	50	1.92	96	63	4.32
15	9	10.80	36	23	9.12	57	37	7.44	77	50	9.84	97	64	0.24
16	10	6.72	37	24	5.04	58	38	3.36	78	51	5.76	98	64	8.12
17	11	2.64	38	25	0.96	59	38	11.28	79	52	1.68	99	65	4.06
18	11	10.56	39	25	8.88	60	39	7.20	80	52	9.60	100	66	0.08
19	12	6.48	40	26	4.80	61	40	3.12	81	53	5.52	101	66	7.90
20	13	2.40	41	27	0.72	62	40	11.04	82	54	1.44	102	67	3.84
21	13	10.32	42	27	8.64									

Table XX

METRIC EQUIVALENTS

Millimeters × .03937 = inches.
Centimeters × .3937 = inches.
Meter = 39.37 inches.
Meters × 3.281 = feet.
Meters per second = 196.86 feet per minute
Kilometers × .621 = miles.
Kilometers × 3280.89 = feet.
Square millimeters × .00155 = square inches.
Square centimeters × .155 = square inches.
Cubic centimeters ÷ 16.383 = cubic inches.
Cubic meters × 35.3165 = cubic feet.
Cubic meters × 264.2 = gallons (231 cubic inches).
Liters × .2642 = gallons (231 cubic inches).
Kilograms × 2.2046 = pounds.
Kilograms per square millimeter × 1422.3 = pounds per square inch.
Kilograms per square cent. × 14.223 = pounds per square inch.
Kilowatts × 1.34 = horse-power.
Watts ÷ 746 = horse-power.
Cheval Vapeur × .9863 = horse-power.
Centigrade × 1.8 + 32 = degrees Fahrenheit.

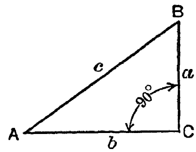


Table XXI

FORMULÆ FOR THE SOLUTION OF RIGHT TRIANGLES

Given.	Required.	Formulæ.
a, A	B, b, c	$B=90°-A$ $b=a \cot A$ $c=\dfrac{a}{\sin A}=a \csc A$
a, B	A, b, c	$A=90°-B$ $b=a \tan B$ $c=\dfrac{a}{\cos B}=a \sec B$
c, A	B, a, b	$B=90°-A$ $a=c \sin A$ $b=c \cos A$
a, b	A, B, c	$\tan A=\dfrac{a}{b}$ $\tan B=\dfrac{b}{a}$, or $B=90°-A$ $c=\sqrt{a^2+b^2}$ $c=\dfrac{a}{\sin A}=a \csc A$
a c	A, B, b	$\sin A=\dfrac{a}{c}$ $\cos B=\dfrac{a}{c}$, or $B=90°-A$ $b=\sqrt{c^2-a^2}=\sqrt{(c+a)(c-a)}$ $b=a \cot A$

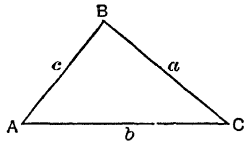


Table XXII

FORMULÆ FOR THE SOLUTION OF OBLIQUE TRIANGLES

Given.	Required.	Formulæ.
a b, C	A, B, c	$\tan \frac{1}{2}(A-B)=\frac{a-b}{a+b}\cot \frac{1}{2}C$ $A=(90°-\frac{1}{2}C)+\frac{1}{2}(A-B)$ $B=(90°-\frac{1}{2}C)-\frac{1}{2}(A-B)$ $c=\frac{(a-b)\cos\frac{1}{2}C}{\sin\frac{1}{2}(A-B)}$ $c=\sqrt{a^2+b^2-2ab\cos C}$
c, A, B	C, a, b	$C=180°-(A+B)$ $a=\frac{c}{\sin C}\sin A$ $b=\frac{c}{\sin C}\sin B$
a, b, A	B, C, c	$\sin B=\frac{b}{a}\sin A$ $C=180°-A-B$ $c=\frac{a}{\sin A}\sin C$
a, b c $\frac{1}{2}(a+b+c)=s$	A	$\tan \frac{1}{2}A=\sqrt{\frac{(s-b)(s-c)}{s(s-a)}}$ $\cos \frac{1}{2}A=\sqrt{\frac{s(s-a)}{bc}}$ $\cos A=\frac{b^2+c^2-a^2}{2bc}$

TABLE XXIII

TRIGONOMETRIC FORMULÆ

$$\sin^2 A + \cos^2 A = 1$$

$$\sin A = 2 \sin \tfrac{1}{2}A \times \cos \tfrac{1}{2}A$$

$$\cos A = 2 \cos^2 \tfrac{1}{2}A - 1 = 1 - 2 \sin^2 \tfrac{1}{2}A$$

$$\tan A = \frac{1 - \cos 2A}{\sin 2A} = \frac{\sin A}{\cos A}$$

$$\sin \tfrac{1}{2}A = \sqrt{\frac{1 - \cos A}{2}}$$

$$\cos \tfrac{1}{2}A = \sqrt{\frac{1 + \cos A}{2}}$$

$$\tan \tfrac{1}{2}A = \frac{1 - \cos A}{\sin A}$$

$$\sin 2A = 2 \sin A \cos A$$

$$\cos 2A = \cos^2 A - \sin^2 A = 2 \cos^2 A - 1$$

$$\tan 2A = \frac{2 \tan A}{1 - \tan^2 A}$$

$$\sin (A \pm B) = \sin A \cos B \pm \sin B \cos A$$

$$\cos (A \pm B) = \cos A \cos B \mp \sin A \sin B$$

$$\sin A + \sin B = 2 \sin \tfrac{1}{2}(A+B) \cos \tfrac{1}{2}(A-B)$$

$$\sin A - \sin B = 2 \cos \tfrac{1}{2}(A+B) \sin \tfrac{1}{2}(A-B)$$

$$\cos A + \cos B = 2 \cos \tfrac{1}{2}(A+B) \cos \tfrac{1}{2}(A-B)$$

$$\cos B - \cos A = 2 \sin \tfrac{1}{2}(A+B) \sin \tfrac{1}{2}(A-B)$$

$$\tan A + \tan B = \frac{\sin (A+B)}{\cos A \cos B}$$

$$\tan A - \tan B = \frac{\sin (A-B)}{\cos A \cos B}$$

$$\sin (A \pm 90°) = \pm \cos A$$

$$\cos (A \pm 90°) = \mp \sin A$$

$$\sin (A \pm 180°) = \sin A$$

$$\cos (A \pm 180°) = \cos A$$

Table XXIV

SINES, COSINES, TANGENTS, COTANGENTS

deg.	sin 0′	tan 0′	sin 10′	tan 10′	sin 20′	tan 20′	sin 30′	tan 30′	sin 40′	tan 40′	sin 50′	tan 50′	deg.
0	0000	0000	0029	0029	0058	0058	0087	0087	0116	0116	0145	0145	89
1	175	0175	0204	0204	0233	0233	0262	262	291	291	320	320	88
2	349	349	378	378	407	407	436	437	465	466	494	495	87
3	523	524	552	553	581	582	610	612	640	641	669	670	86
4	698	699	727	729	756	758	785	787	814	816	843	846	85
5	872	875	901	904	929	934	958	963	987	992	1016	1022	84
6	1045	1051	1074	1080	1103	1110	1132	1139	1161	1169	190	198	83
7	219	228	248	257	279	287	305	317	334	346	363	376	82
8	392	405	421	435	449	465	478	495	507	524	536	554	81
9	564	584	593	614	622	644	650	673	679	703	708	733	80
10	736	763	765	793	794	823	822	853	851	883	880	914	79
11	908	944	937	974	965	2004	994	2035	2022	2065	2051	2095	78
12	2079	2126	2108	2156	2136	186	2164	217	193	247	221	278	77
13	250	309	278	339	306	370	334	401	363	432	391	462	76
14	419	493	447	524	476	555	504	586	532	617	560	648	75
15	588	679	616	711	644	742	672	773	700	805	728	836	74
16	756	86	784	899	812	931	840	962	868	994	896	3026	73
17	924	3057	952	3089	939	3121	3007	3153	3035	3185	3062	217	72
18	3090	249	3118	281	3145	314	173	346	201	378	228	411	71
19	256	443	283	476	311	508	338	541	365	574	393	607	70
20	420	640	448	673	475	706	502	739	529	772	557	905	69
21	584	839	611	872	638	906	665	939	692	973	719	4006	68
22	746	4040	773	4074	800	4108	827	4142	854	4176	881	210	67
23	907	245	934	279	961	314	987	348	4014	383	4041	417	66
24	4067	452	4094	487	4120	522	4147	557	173	592	200	628	65
25	226	663	253	699	279	734	305	770	331	806	358	841	64
26	384	877	410	913	436	950	4462	986	488	5022	514	5059	63
27	540	5095	566	5132	592	5169	617	5206	643	243	669	280	62
28	695	317	720	354	746	392	772	430	797	467	823	505	61
29	848	543	874	581	899	619	924	658	950	696	975	735	60
30	5000	774	5025	5812	5050	851	5075	890	100	930	5125	969	59
31	150	6009	175	6048	200	6088	225	6128	250	6168	275	6208	58
32	299	249	324	289	348	330	5373	371	398	412	422	453	57
33	446	494	471	536	495	577	519	619	544	661	568	703	56
34	592	745	616	787	640	830	664	873	688	916	712	959	55
deg.	60′ cos	60′ cot	50′ cos	50′ cot	40′ cos	40′ cot	30′ cos	30′ cot	20′ cos	20′ cot	10′ cos	10′ cot	deg.

TABLE XXIV—*Continued*

deg.	sin 0′	tan 0′	sin 10′	tan 10′	sin 20′	tan 20′	sin 30′	tan 30′	sin 40′	tan 40′	sin 50′	tan 50′	deg.
35	736	.7002	760	7046	783	7089	807	7133	831	7177	854	7221	54
36	878	265	901	310	925	355	948	400	972	445	995	490	53
37	6018	536	6041	581	6065	627	6088	673	6111	720	6134	766	52
38	157	813	180	860	202	907	225	954	248	8002	271	8050	51
39	293	8098	316	8146	338	8195	361	8243	383	292	406	342	50
40	428	391	450	441	472	491	494	541	517	591	539	642	49
41	561	693	583	744	604	796	626	847	648	899	670	952	48
42	691	9004	713	9057	734	9110	756	9163	777	9217	799	9271	47
43	820	325	841	380	862	435	884	490	905	545	926	601	46
44	947	657	967	713	988	770	7009	827	7030	884	7050	942	45
45	7071	1.0000	7092	1.0058	7112	1.0117	133	1.0176	153	1.0235	173	1.0295	44
46	7193	1.0355	7214	1.0416	7234	1.0477	7254	1.0533	7274	1.0599	7294	1.0661	43
47	314	.0724	333	.0786	353	.0850	373	.0913	392	.0977	412	.1041	42
48	431	.1106	451	.1171	470	.1237	490	.1303	509	.1369	528	.1436	41
49	547	.1504	566	.1571	585	.1640	604	.1708	623	.1778	642	.1847	40
50	660	1.1918	7679	1.1988	7698	1.2059	7716	1.2131	7735	1.2203	7753	1.2276	39
51	771	.2349	790	.2423	808	.2497	826	.2572	844	.2647	862	.2723	38
52	880	.2799	898	.2876	916	.2954	934	.3032	951	.3111	969	.3190	37
53	986	.3270	8004	.3351	8021	.3452	8039	.3514	8056	.3597	8073	.3680	36
54	8090	.3764	107	.3848	124	.3934	141	.4019	158	.4106	175	.4193	35
55	192	.4281	208	.4370	225	.4460	241	.4550	258	.4641	274	.4733	34
56	290	.4826	307	.4919	323	.5013	339	.5108	355	.5204	371	.5301	33
57	387	.5399	403	.5497	418	.5597	434	.5697	450	.5798	465	.5900	32
58	480	.6003	496	.6107	511	.6212	526	.6319	542	.6426	557	.6534	31
59	572	.6643	587	.6753	601	.6864	616	.6977	631	.7090	646	.7205	30
60	660	1.7321	8675	1.7437	8689	1.7556	8704	1.7675	8718	1.7797	8732	1.7917	29
61	746	.8040	760	.8165	774	.8291	788	.8418	802	.8546	816	.8676	28
62	829	.8807	843	.8940	857	.9074	870	.9210	884	.9347	897	.9486	27
63	910	.9626	923	.9768	936	.9912	949	2.0057	962	2.0204	975	2.0353	26
64	988	2.0503	9001	2.0655	9013	2.0809	9026	.0965	9038	.1123	9051	.1283	25
65	9063	.1445	075	.1609	088	.1775	100	.1943	112	.2113	124	.2286	24
66	135	.2460	147	.2637	159	.2817	171	.2998	182	.3183	194	.3369	23
67	205	.3559	216	.3750	228	.3945	239	.4142	250	.4342	261	.4545	22
68	272	.4751	283	.4960	293	.5172	304	.5386	315	.5605	325	.5826	21
69	336	.6051	346	.6279	356	.6511	367	.6746	377	.6985	387	.7228	20
deg.	60′ cos	60′ cot	50′ cos	50′ cot	40′ cos	40′ cot	30′ cos	30′ cot	20′ cos	20′ cot	10′ cos	10′ cot	deg.

Table XXIV—*Continued*

deg.	sin 0′	tan 0′	sin 10′	tan 10′	sin 20′	tan 20′	sin 30′	tan 30′	sin 40′	tan 40′	sin 50′	tan 50′	deg.
70	397	2.7475	9407	2.7725	9417	2.7980	9426	2.8239	9436	2.8502	9446	2.8770	19
71	455	.9042	465	.9319	474	.9600	483	.9887	492	3.0178	502	3.0475	18
72	511	3.0777	520	3.1084	528	3.1397	537	3.1716	546	.2041	555	.2371	17
73	563	.2709	572	.3052	580	.3402	588	.3759	596	.4124	605	.4495	16
74	613	.4874	621	.5261	628	.5656	636	.6059	644	.6470	652	.6891	15
75	659	.7321	667	.7760	674	.8208	681	.8657	689	.9136	696	.9617	14
76	703	4.0108	710	4.0611	717	4.1126	724	4.1653	730	4.2193	737	4.2747	13
77	744	.3315	750	.3897	757	.4494	763	.5107	769	.5736	775	.6382	12
78	781	.7046	787	.7729	793	.8430	799	.9152	805	.9894	811	5.0658	11
79	816	.1446	822	5.2257	827	5.3093	833	5.3955	838	5.4845	843	.5764	10
80	9848	5.6713	9853	5.7694	9858	5.8708	9863	5.9758	9868	6.0844	9872	6.1970	9
81	877	6.3138	881	6.4348	886	6.5606	890	6.6912	894	.8269	899	.9682	8
82	903	7.1154	907	7.2687	911	7.4287	914	7.5958	918	7.7704	922	7.9530	7
83	925	8.1443	929	8.3450	932	8.5555	936	8.7769	939	9.0098	942	9.2553	6
84	945	9.5144	948	9.7882	951	10.078	954	10.385	957	10.711	959	11.059	5
85	962	11.430	964	11.826	967	12.250	969	12.706	971	13.197	974	13.727	4
86	976	14.300	978	14.924	980	15.605	981	16.350	983	17.169	985	18.075	3
87	986	19.081	988	20.206	989	21.470	990	22.903	992	24.542	993	26.432	2
88	994	28.636	9995	31.242	9996	34.368	997	38.189	997	42.964	9998	49.104	1
89	9998	57.290	9999	68.750	9999	85.940	9999	114.58	1.00	171.88	1.00	343.77	0
deg	60′ cos	60′ cot	50′ cos	50′ cot	40′ cos	40′ cot	30′ cos	30′ cot	20′ cos	20′ cot	10′ cos	10′ cot	deg.

Table XXV

TEXAS LAND MEASURE

(Also Used in Mexico, New Mexico, Arizona, and California)

26,000,000	sq. varas (square of 5099	varas) = 1 league and 1 labor	= 4605.5	acres.
1,000,000	sq. varas (square of 1000	varas) = 1 labor	= 177.136	acres.
25,000,000	sq. varas (square of 5000	varas) = 1 league	= 4428.4	acres.
12,500,000	sq. varas (square of 3535.5	varas) = ½ league	= 2214.2	acres.
8,333,333	sq. varas (square of 2886.7	varas) = ⅓ league	= 1476.13	acres.
6,250,000	sq. varas (square of 2500	varas) = ¼ league	= 1107.1	acres.
7,225,600	sq. varas (square of 2688	varas)	= 1280	acres.
3,612,800	sq. varas (square of 1900.8	varas) = 1 section	= 640	acres.
1,860,400	sq. varas (square of 1344	varas) = ½ section	= 320	acres.
903,200	sq. varas (square of 950.44	varas) = ¼ section	= 160	acres.
451,600	sq. varas (square of 672	varas) = ⅛ section	= 80	acres.
225,800	sq. varas (square of 475	varas) = $\frac{1}{16}$ section	= 40	acres.
5,645.376	sq. varas (square of 75.137	varas) = 4840 square yards	= 1	acre.

To find the number of acres in any number of square varas, multiply the latter by 177 (or to be more exact, by 177⅛), and cut off six decimals.

1 vara = 33⅓ inches. 1900.8 varas = 1 mile.

Table XXVI

BAUMÉ GRAVITY AND TEMPERATURE

Grav-ities.	Temperatures.											
	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
20	21.5	21.1	20.8	20.5	20.3	20.0	19.7	19.4	19.1	18.9	18.6	18.4
21	22.5	22.1	21.8	21.5	21.3	21.0	20.7	20.4	20.1	19.8	19.6	19.3
22	23.6	23.2	22.8	22.5	22.3	22.0	21.7	21.4	21.1	20.8	20.5	20.3
23	24.6	24.2	23.9	23.6	23.3	23.0	22.7	22.4	22.1	21.8	21.5	21.2
24	25.6	25.2	24.9	24.6	24.3	24.0	23.7	23.4	23.1	22.8	22.5	22.2
25	26.6	26.3	25.9	25.6	25.3	25.0	24.7	24.3	24.0	23.7	23.5	23.2
26	27.7	27.3	26.9	26.6	26.3	26.0	25.7	25.3	25.0	24.7	24.4	24.1
27	28.7	28.3	28.0	27.6	27.3	27.0	26.7	26.3	26.0	25.7	25.4	25.1
28	29.7	29.3	29.0	28.6	28.3	28.0	27.7	27.3	27.0	26.7	26.4	26.0
29	30.7	30.4	30.0	29.7	29.3	29.0	28.7	28.3	28.0	27.6	27.3	27.0
30	31.8	31.4	31.0	30.7	30.3	30.0	29.7	29.3	29.0	28.6	28.3	28.0
31	32.8	32.4	32.1	31.7	31.3	31.0	30.6	30.3	29.9	29.6	29.3	28.9
32	33.8	33.5	33.1	32.7	32.4	32.0	31.6	31.3	30.9	30.6	30.2	29.9
33	34.9	34.5	34.1	33.7	33.4	33.0	32.6	32.3	31.9	31.6	31.2	30.8
34	35.9	35.5	35.1	34.8	34.4	34.0	33.6	33.3	32.9	32.5	32.2	31.8
35	36.9	36.5	36.2	35.8	35.4	35.0	34.6	34.3	33.9	33.5	33.1	32.7
36	38.0	37.6	37.2	36.8	36.4	36.0	35.6	35.2	34.9	34.5	34.1	33.7
37	39.0	38.6	38.2	37.8	37.4	37.0	36.6	36.2	35.8	35.5	35.1	34.7
38	40.0	39.6	39.2	38.8	38.4	38.0	37.6	37.2	36.8	36.4	36.0	35.6
39	41.0	40.6	40.2	39.8	39.4	39.0	38.6	38.2	27.8	37.4	37.0	36.6
40	42.1	41.6	41.2	40.8	40.4	40.0	39.6	39.2	38.8	38.4	38.0	37.6
41	43.1	42.7	42.3	41.8	41.4	41.0	40.6	40.2	39.8	39.4	38.9	38.5
42	44.1	43.7	43.3	42.9	42.4	42.0	41.6	41.2	40.8	30.4	39.9	39.5
43	45.2	44.7	44.3	43.9	43.4	43.0	42.6	42.2	41.7	41.3	40.9	40.5
44	46.2	45.7	45.3	44.9	44.4	44.0	43.6	43.1	42.7	42.3	41.9	41.4
45	47.2	46.8	46.3	45.9	45.5	45.0	44.6	44.1	43.7	43.3	42.8	42.4
46	48.3	47.8	47.3	46.9	46.5	46.0	45.5	45.1	44.7	44.2	43.8	43.4
47	49.3	48.8	48.4	47.9	47.5	47.0	46.5	46.1	45.7	45 2	44.8	44.4
48	50.4	49.9	49.4	48.9	48.5	48.0	47.5	47.1	46.6	46.2	45.7	45.3
49	51.4	50.9	50.4	50.0	49.5	49.0	48.5	48.1	47 6	47.2	46.7	46.3
50	52.5	52.0	51.5	51.0	50.5	50.0	49.5	49.1	48.6	48.1	47.7	47.3
51	53.5	53.0	52.5	52.0	51.5	51.0	50.5	50.1	49.6	49.1	48.6	48.2
52	54.6	54.0	53.5	53.0	52.5	52.0	51.5	51.0	50.5	50.1	49.6	49.2
53	55.6	55.1	54.5	54.0	53.5	53.0	52.5	52.0	51.5	51.0	50.6	50.1
54	56.7	56.1	55 6	55.0	54.5	54.0	53.5	53.0	52.5	52.0	51.5	51.1

TABLE XXVI—*Continued*

Gravities.	Temperatures.											
	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
55	57.7	57.1	56.6	56.1	55.5	55.0	54.5	54.0	53.5	53.0	52.5	52.0
56	58.8	58.2	57.6	57.1	56.5	56.0	55.5	55.0	54.4	53.9	53.4	53.0
57	59.8	59.2	58.7	58.1	57.5	57.0	56.5	55.9	55.4	54.9	54.4	53.9
58	60.9	60.3	59.7	59.1	58.5	58.0	57.5	56.9	56.4	55.9	55.4	54.9
59	61.9	61.3	60.7	60.1	59.6	59.0	58.5	57.9	57.4	56.8	56.3	55.8
60	63.0	62.3	61.7	61.1	60.6	60.0	59.4	58.9	58.3	57.8	57.3	56.8
61	64 0	63.4	62.8	62.2	61.6	61.0	60.4	59.9	59.3	58.8	58.3	57.7
62	65.1	64.4	63.8	63.2	62.6	62.0	61.4	60.9	60.3	59.7	59.2	58.7
63	66.1	65.5	64.8	64.2	63.6	63.0	62.4	61.8	61.3	60.7	60.2	59.6
64	67.2	66.5	65.8	65.2	64.6	64.0	63.4	62.8	62.3	61.7	61.1	60.6
65	68.2	67.5	66.9	66.2	65.6	65.0	64.4	63.8	63.2	62.6	62.1	61.5
66	69.3	68.6	67.9	67.2	66.6	66.0	65.4	64.8	64.2	63.6	63.0	62.5
67	70.3	69.6	69.0	68.3	67.6	67.0	66.4	65.8	65.2	64.6	64.0	63.4
68	71.4	70.7	69.9	69.3	68.6	68.0	67.4	66.7	66.1	65.5	64.9	64.4
69	72.5	71.7	71.0	70.3	69.6	69.0	68.4	67.7	67.1	66.5	65.9	65.3
70	73.5	72.7	72.0	71.3	70.6	70.0	69.4	68.7	68.1	67.5	66.9	66.3
71	74.6	73.8	73.0	72.3	71.7	71.0	70.3	69.7	69.1	68.4	67.8	67.2
72	75.6	74.8	74.1	73.3	72.7	72.0	71.3	70.7	70.0	69.4	68.8	68.2
73	76.7	75.9	75.1	74.4	73.7	73.0	72.3	71.7	71.0	70.3	69.7	69.1
74	77.7	76.9	76.1	75.4	74.7	74.0	73.3	72.6	72.0	71.3	70.7	70.1
75	78.7	77.9	77.2	76.4	75.7	75.0	74.3	73.6	72.9	72.3	71.6	71.0
76	79.7	78.9	78.2	77.4	76.7	76.0	75.3	74.6	73.9	73.2	72.6	71.9
77	80.7	80.0	79.2	78.4	77.7	77.0	76.3	75.6	74.9	74.2	73.5	72.9
78	81.8	81.0	80.2	79.5	78.7	78.0	77.3	76.5	75.8	75.1	74.5	73.8
79	82.8	82.0	81.2	80.5	79.7	79.0	78.3	77.5	76.8	76.1	75.4	74.8
80	83.8	83.0	82.3	81.5	80.7	80.0	79.3	78.5	77.8	77.1	76.4	75.7
81	84.8	84.1	83.3	82.5	81.8	81.0	80.3	79.5	78.8	78.1	77.4	76.6
82	85.8	85.1	84.3	83.5	82.8	82.0	81.2	80.5	79.8	79.1	78.4	77.6
83	86.9	86.1	85.3	84.6	83.8	83.0	82.2	81.5	80.8	80.1	79.3	78.6
84	87.9	87.1	86.4	85.6	84.8	84.0	83.2	82.5	81.7	81.0	80.3	79.6
85	88.9	88.1	87.4	86.6	85.8	85.0	84.2	83.5	82.7	82.0	81.3	80.6
86	89.9	89.2	88.4	87.6	86.8	86.0	85.2	84.4	83.7	83.0	82.3	81.6
87	90.9	90.2	89.4	88.6	87.8	87.0	86.2	85.4	84.7	84.0	83.3	82.6
88	91.9	91.2	90.5	89.6	88.8	88.0	87.2	86.4	85.7	85.0	84.3	83.6
89	93.0	92.2	91.5	90.7	89.8	89.0	88.2	87.4	86.7	86.0	85.3	84.6
90	94.0	93.2	92.5	91.7	90.8	90.0	89.1	88.4	87.7	87.0	86.3	85.6

TABLE XXVII

WEIGHT AND GRAVITY

LIQUIDS LIGHTER THAN WATER AT 60° F.

Degrees Baumé.	Specific Gravity.	Actual Weight per Gallon.	Billing Weight per Gallon.	Degrees Baumé.	Specific Gravity.	Actual Weight per Gallon.	Billing Weight per Gallon.
10	1.0000	8.32	......	43	0.8092	6.74	6¾
11	0.9929	8.27	......	44	0.8045	6.70	6⅝
12	0.9859	8.21	......	45	0.8000	6.66	6⅝
13	0.9799	8.16	......	46	0.7951	6.63	6⅝
14	0.9722	8.10	......	47	0.7909	6.59	6½
15	0.9655	8.04	......	48	0.7865	6.55	6½
16	0.9589	7.99	......	49	0.7821	6.52	6½
17	0.9523	7.93	......	50	0.7777	6.48	6⅜
18	0.9459	7.88	......	51	0.7734	6.44	6⅜
19	0.9395	7.83	......	52	0.7692	6.41	6⅜
20	0.9333	7.78	......	53	0.7650	6.37	6⅜
21	0.9271	7.72	......	54	0.7608	6.34	6¼
22	0.9210	7.67	......	55	0.7567	6.30	6¼
23	0.9150	7.62	7½	56	0.7526	6.27	6¼
24	0.9090	7.57	7½	57	0.7486	6.24	6¼
25	0.9032	7.53	7½	58	0.7446	6.20	6⅛
26	0.8974	7.48	7⅜	59	0.7407	6.17	6⅛
27	0.8917	7.43	7⅜	60	0.7368	6.14	6⅛
28	0.8860	7.38	7⅜	61	0.7329	6.11	6⅛
29	0.8805	7.34	7¼	62	0.7290	6.07	6
30	0.8750	7.29	7¼	63	0.7253	6.04	6
31	0.8695	7.24	7¼	64	0.7216	6.01	6
32	0.8641	7.20	7⅛	65	0.7179	5.98	6
33	0.8588	7.15	7⅛	66	0.7142	5.95	5⅞
34	0.8536	7.11	7⅛	67	0.7106	5.92	5⅞
35	0.8484	7.07	7	68	0.7070	5.89	5⅞
36	0.8433	7.03	7	69	0.7035	5.86	5⅞
37	0.8383	6.98	7	70	0.7000	5.83	5¾
38	0.8333	6.94	6⅞	75	0.6829	5.69	5¾
39	0.8284	6.90	6⅞	80	0.6666	5.55	5½
40	0.8235	6.86	6⅞	85	0.6511	5.42	5⅜
41	0.8187	6.82	6¾	90	0.6363	5.30	......
42	0.8139	6.78	6¾	95	0.6222	5.18	......

This table is calculated for a temperature of 60° F. and is based on the formulæ:

$$\frac{140}{\text{Bé.}^\circ + 130} = \text{specific gravity and } \frac{140}{\text{Specific gravity}} - 130 = \text{Bé.}^\circ$$

Table XXVIII

DAILY CAPACITY OF GAS WELLS

Pressure by			Diameter of Opening.							
Water Gauge, Inches.	Mercury Gauge, Inches.	Pressure Gauge, Lb. per Sq. In.	1″.	2″.	3″.	4″.	5–5 3/16″.	6¼″.	6⅝″.	8¼″.
.1	....	....	12,000	48,000	108,000	192,000	300,000	453,600	507,000	783,360
.2	....	....	16,848	67,392	151,632	269,568	421,200	636,854	711,828	1,099,772
.3	....	....	20,760	83,040	186,840	332,160	519,000	784,728	877,110	1,355,212
.4	....	....	23,640	94,560	212,760	378,240	591,000	893,592	998,790	1,543,219
.5	....	....	26,448	105,792	238,032	423,168	661,200	999,734	1,117,428	1,726,525
.6	....	....	28,992	115,968	260,928	463,872	724,800	1,095,897	1,224,912	1,892,597
.7	....	....	31,560	126,240	284,040	504,960	789,000	1,192,968	1,301,850	2,062,368
.8	....	....	33,600	134,400	302,400	537,600	840,000	1,270,080	1,419,600	2,193,408
.9	....	....	35,760	143,040	321,840	572,160	894,000	1,351,728	1,510,860	2,334,412
1.0	....	....	37,680	150,720	339,120	602,880	942,000	1,424,304	1,591,980	2,459,750
1.25	....	....	42,240	168,960	380,160	675,840	1,056,000	1,596,672	1,784,640	2,757,427
1.34	.1	....	44,040	176,160	396,360	704,640	1,101,000	1,664,712	1,860,690	2,874,931
1.5	.11	....	46,080	184,320	414,720	737,280	1,152,000	1,741,824	1,946,880	3,008,102
1.75	.13	....	49,800	199,200	448,200	796,800	1,245,000	1,882,440	2,104,050	3,250,944
2.00	.15	....	53,280	213,120	479,520	852,480	1,332,000	2,013,984	2,251,080	3,478,118
2.5	.18	....	59,520	238,080	535,680	952,320	1,488,000	2,249,856	2,514,720	3,885,465
2.69	.20	....	62,160	248,640	559,440	994,560	1,554,000	2,349,648	2,626,260	4,057,804
3.0	.22	....	65,160	260,640	586,440	1,042,560	1,629,000	2,463,048	2,753,010	4,253,644
3.5	.26	....	70,392	281,568	633,528	1,126,272	1,759,800	2,660,817	2,974,062	4,595,189
4.04	.30	....	76,080	304,320	684,720	1,217,280	1,902,000	2,875,824	3,214,380	4,966,502

TABLE XXVIII—*Continued*

Pressure by			Diameter of Opening.							
Water Gauge, Inches.	Mercury Gauge, Inches.	Pressure Gauge, Lb. per Sq. In.	1″.	2″.	3″.	4″.	5–5 3/16″.	6¼″.	6⅝″.	8¼″.
4.5	.33	....	79,920	319,680	719,280	1,278,720	1,998,000	3,020,976	3,376,620	5,217,177
5.0	.37	....	82,680	330,720	744,120	1,322,880	2,067,000	3,125,304	3,493,230	5,397,350
5.39	.40	....	87,720	350,880	789,480	1,403,520	2,193,000	3,315,816	3,706,170	5,726,361
6.0	.44	....	92,160	368,640	829,440	1,474,560	2,304,000	3,483,648	3,893,760	6,016,204
6.74	.50	....	98,280	393,120	884,520	1,572,480	2,457,000	3,714,984	4,152,330	6,415,718
8.08	.60	....	107,760	431,040	969,840	1,724,160	2,694,000	4,073,328	4,552,860	7,034,572
9.00	.66	....	113,040	452,160	1,017,360	1,808,640	2,826,000	4,272,912	4 770,940	7,379,251
9.43	.70	....	116,400	465,600	1,047,600	1,862,400	2,910,000	4,399,920	4,817,900	7,598,592
10.00	.74	....	119,040	476,160	1,071,360	1,904,640	2,976,000	4,499,712	5,029,440	7,770,931
10.78	.80	....	124,320	497,280	1,118,880	1,989,120	3,108,000	4,699,296	5,252,520	8,115,609
12.00	.88	....	130,320	521 280	1,172,880	2.085,120	3,258,000	4,926,096	5,516,020	8,507,289
12.13	.90	....	131,880	527,520	1,186,920	2,110,080	3,297,000	4,985,064	5,571,930	8,609,126
13.75	1.02	.50	138,600	554,400	1,247,400	2,217,600	3,465,000	5,239,080	5,856,850	9,047,808
20.22	1.50	.73	170,280	681,120	1,532,520	2,724.480	4,257,000	6,436,584	7,194,330	11,115,875
26.96	2.00	.98	196,680	786,720	1,770,120	3,146,880	4,917,000	7,434,504	8,309,730	12,839,270
33.70	2.50	1.22	219,960	879,840	1,979,640	3.519,360	5,499 000	8,314,488	9,293,310	14,358,988
40.44	3.00	1.47	240,720	962,880	2,166,480	3,851,520	6,018,000	9,099,216	10,170,420	15,714,201
47.18	3.50	1.71	259,920	1,039,680	2,339,280	4,158,720	6,498,000	9,824,970	10,981,620	16,967,577
53.92	4.00	1.96	277,200	1,108,800	2,494,800	4,435,200	6,930,000	10,478,160	11,711.700	18,095,616
60.66	4.50	2.20	294,600	1,178,650	2,651,760	4,714,240	7,366,000	11,135,880	12,448,530	19,231,488

TABLE XXVIII—*Continued*

Pressure by			Diameter of Opening.							
Water Gauge, Inches.	Mercury Gauge, Inches.	Pressure Gauge, Lb. per Sq. In.	1″.	2″.	3″.	4″.	5–5 1/16″.	6¼″.	6⅝″.	8¼″.
67.40	5.00	2.45	310,800	1,243,200	2,797,200	4,972,800	7,770,000	11,748,240	13,131,300	20,289,024
74.14	5.50	2.69	325,800	1,303,200	2,932,200	5,212,800	8,145,000	12,315,240	13,765,050	21,268,224
80.88	6.00	2.94	340,200	1,360,800	3,061,800	5,443,200	8,505 000	12,859,560	14,373,450	22,208,256
87.62	6.50	3.18	354,200	1,416,480	3,187,080	5,665,920	8,853,000	13,385,736	14,961,570	23,116,953
94.36	7.00	3.43	367,680	1,470,720	3,309,120	5,882,880	9,192,000	13,898,304	15,533,480	24,002,150
101.10	7.50	3.67	380,400	1,521,600	3,423,600	6,086,400	9,510,000	14,379,120	16,071,900	24,832,512
107.84	8.00	3.92	392,880	1,571,520	3,535,920	6,286,080	9,822,000	14,850,864	16,599,180	25,647,206
114.58	8.50	4.16	405,000	1,620,000	3,645,000	6,480,000	10,125,000	15,309,000	17,111,250	26,438,400
121.32	9.00	4.41	416,640	1,666,650	3,749,760	6,666,240	10,416,000	15,748,992	17,603,040	27,198,259
128.06	9.50	4.61	428,280	1,713,120	3,854,520	6,852,480	10,707,000	16,188,984	18,095,460	27,958,118
134.80	10.00	4.90	439,920	1,759,680	3,959,280	7,038,720	10,998,000	16,604,784	18,586,620	28,717,977
164.46	12.20	6.00	476,040	1,904,150	4,284,360	7,616,640	11,901,000	17,994,312	20,112,690	31,075,891
	14.23	7.00	517,320	2,069,280	4,665,880	8,277,120	12,933,000	19,554,696	21,856,770	33,770,649
	16.26	8.00	542,400	2,169,600	4,881,600	8,678,400	13,560,000	20,502,720	22,916,400	35,407,872
	18.30	9.00	569,640	2,278,560	5,126,760	9,114,240	14,241,000	21,532,392	24,067,290	37,186,099
	20.33	10.00	595,440	2,381,760	5,358,960	9,527,040	14,886,000	22,507,632	25,157,340	38,870,032
	22.36	11.00	621,960	2,487,840	5,597,640	9,951,360	15,549,000	23,510,088	26,277,810	40,601,548
	24.39	12.00	642,600	2,570,400	5,783,400	10,281,600	16,065,000	24,290,280	27,149,850	41,948,928
	26.43	13.00	664,680	2,658,720	5,982,120	10,634,880	16,617,000	25,124,904	27,933,177	43,390,310
	28.46	14.00	683,880	2,735,520	6,154,920	10,942,080	17,097,000	25,850,664	28,893,930	44,643,686

TABLE XXVIII—*Continued*

Pressure by			Diameter of Opening.							
Water Gauge, Inches.	Mercury Gauge, Inches.	Pressure Gauge, Lb. per Sq. In.	1".	2".	3".	4".	5-5 3/16".	6 1/4".	6 5/8".	8 1/4".
	30.50	15.00	704,520	2,818,080	6,340,680	11,272,320	17,613,000	26,630,856	29,765,970	45,991,065
	32.53	16.00	720,720	2,882,880	6,486,480	11,531,520	18,018,000	27,243,216	30,460 430	47,048,601
	36.60	18.00	750,240	3,000,960	6,752,160	12,003,840	18,756,000	28,359,072	31,697,640	48,975,667
	40.66	20.00	785,520	3,142,080	7,069,680	12,568,320	19,638,000	29,692,656	33,188,220	51,278,745
	44.73	22.00	803,280	3,213,120	7,229,520	12,852,480	20,082,000	30,363,984	33,938,580	52,437,676
	50.81	25.00	854,880	3,419,520	7,693,920	13,678,080	21,372,000	32,314,464	36,718,680	55,806,124
	61.00	30.00	910,920	3,643,680	8,198,280	14,574,720	22,773 000	34,432,776	38,486,370	59,464,415
	71.16	35.00	960,960	3,843,840	8,648,640	15,375,360	24,024,000	36,324,288	40,600,560	62,731,027
	81.33	40.00	1,006,680	4,026,720	9,060,120	16,106,880	25,167,000	38,052,504	42,532,230	65,715,628
	91.50	45.00	1,046,520	4,186,080	9,418,680	16,774,320	26,163,000	39,558,456	44,215,470	68,316,383
		50.00	1,081,920	4,327,680	9,737,280	17,310,720	27,048,000	40,896,576	45,711,120	70,627,295
		60.00	1,137,120	4,548,480	10,234,080	18,193,920	28,428,000	42,983,136	48,043,320	74,230,751
		75.00	1,223,400	4,893,600	11,010,600	19,574,400	30,585,000	46,244,450	51,688,650	79,863,110
		90.00	1,304,400	5,217,600	11,739,600	20,870,400	32,610,000	49,306,320	55,110,900	85,150,790
		100.00	1,336,920	5,347,680	12,032,280	21,390,720	33,422,000	50,535,576	56,484,860	87,273,695
		110.00	1,369,320	5,477,280	12,323,880	21,909,120	34,233,000	51,760,296	57,853,770	89,388,767
		120.00	1,401,720	5,606,880	12,615,480	22,427,520	35,043,000	52,985,016	59,222,670	91,504,281

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